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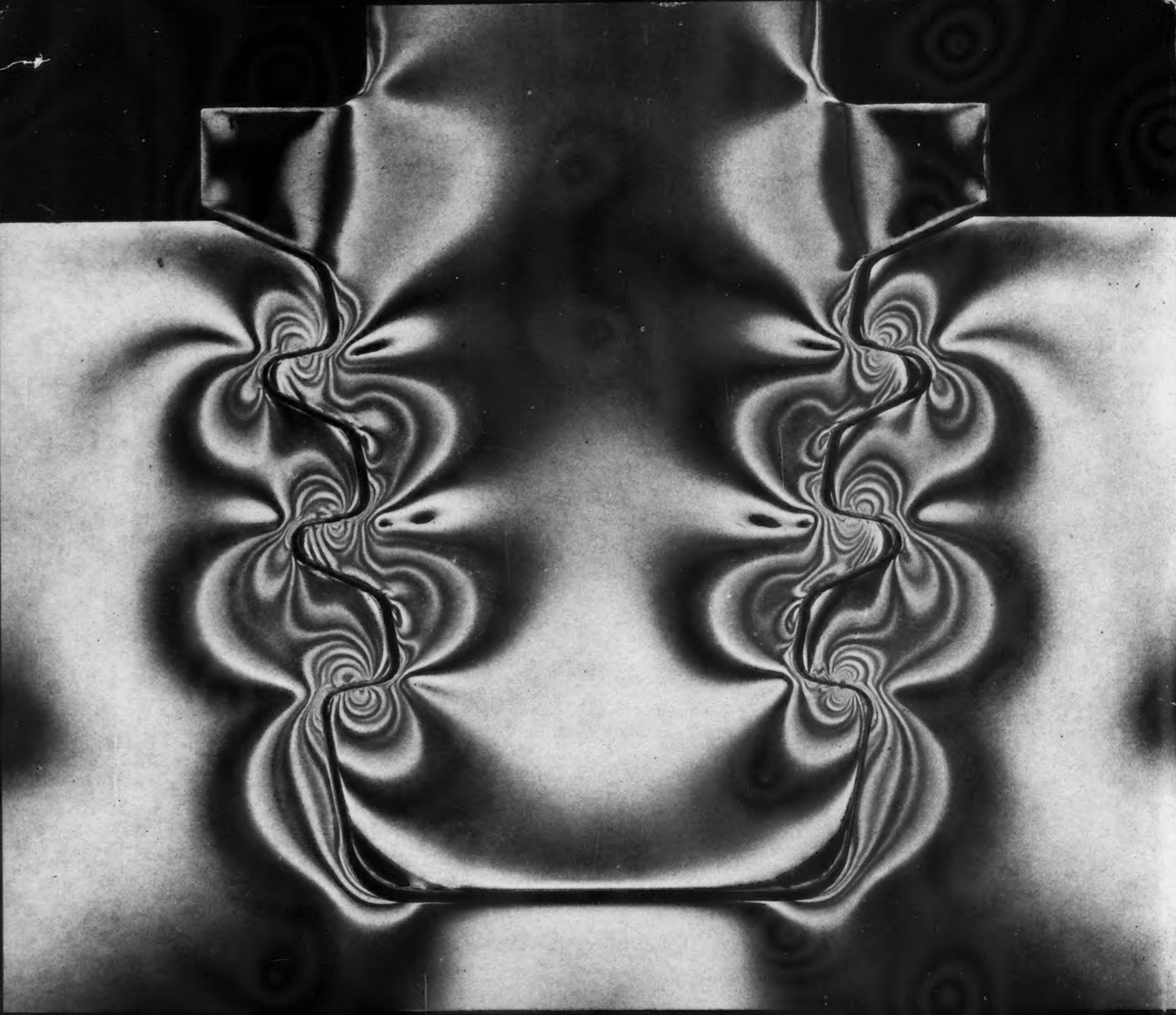


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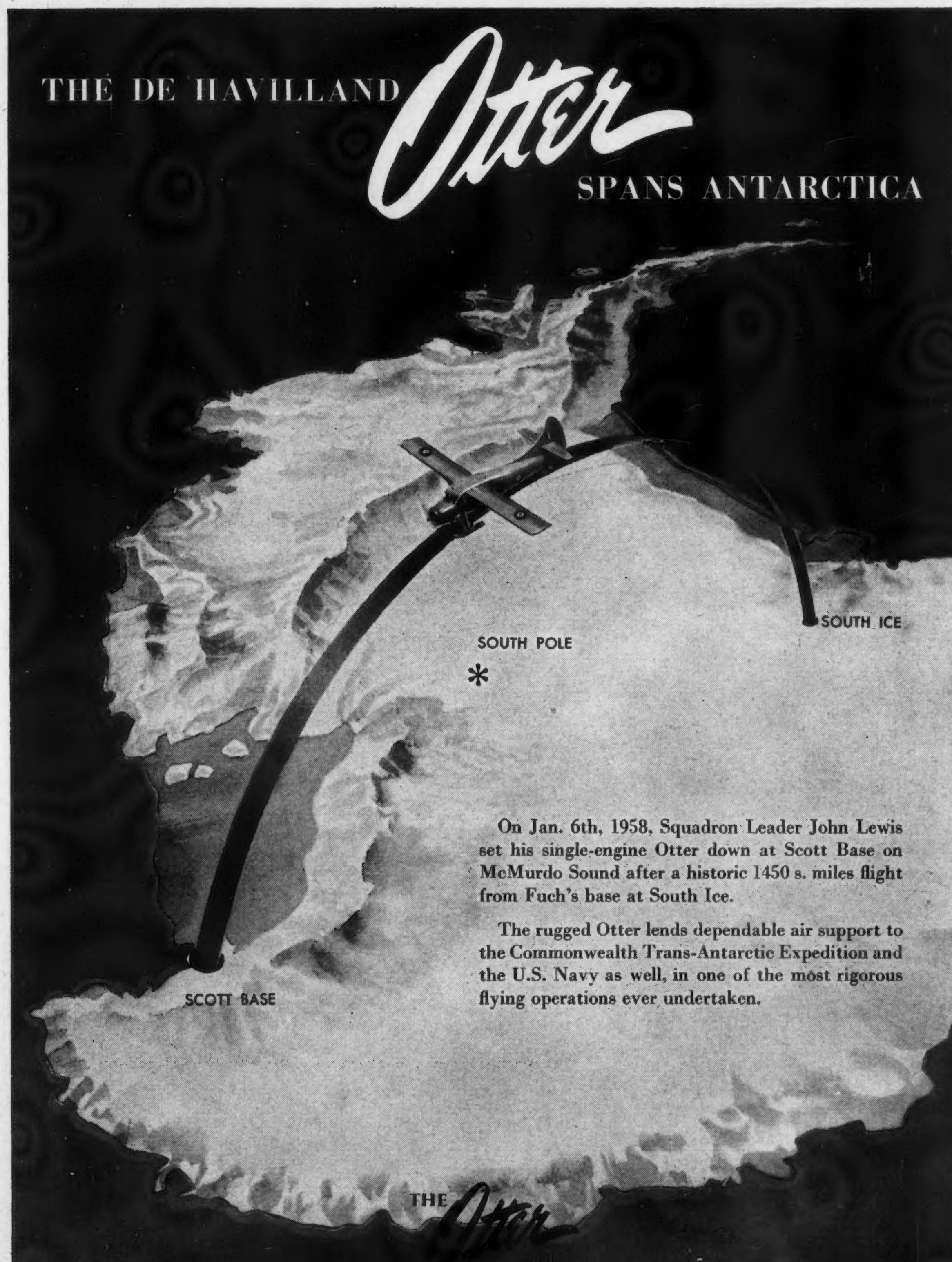


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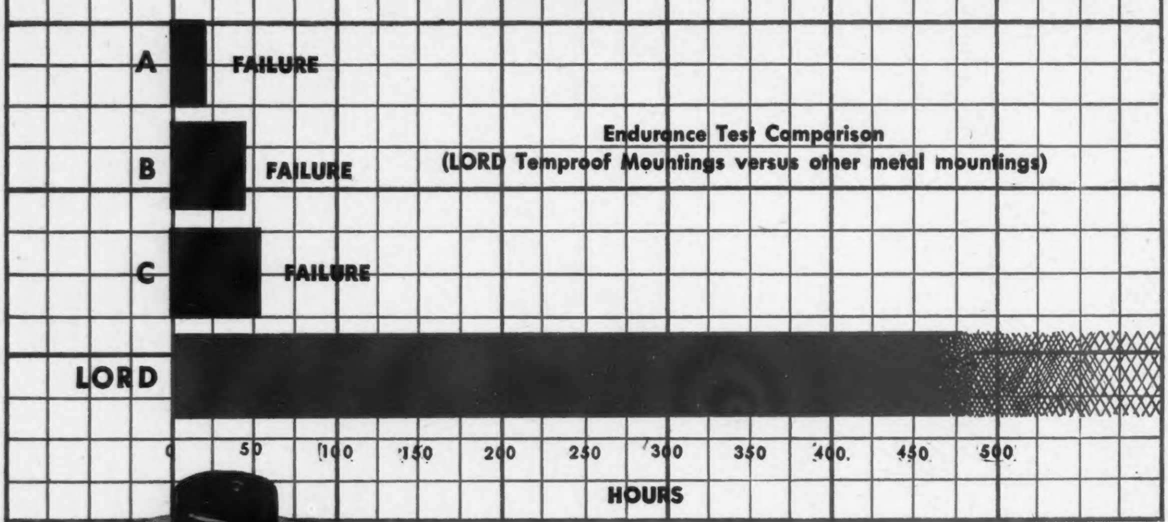



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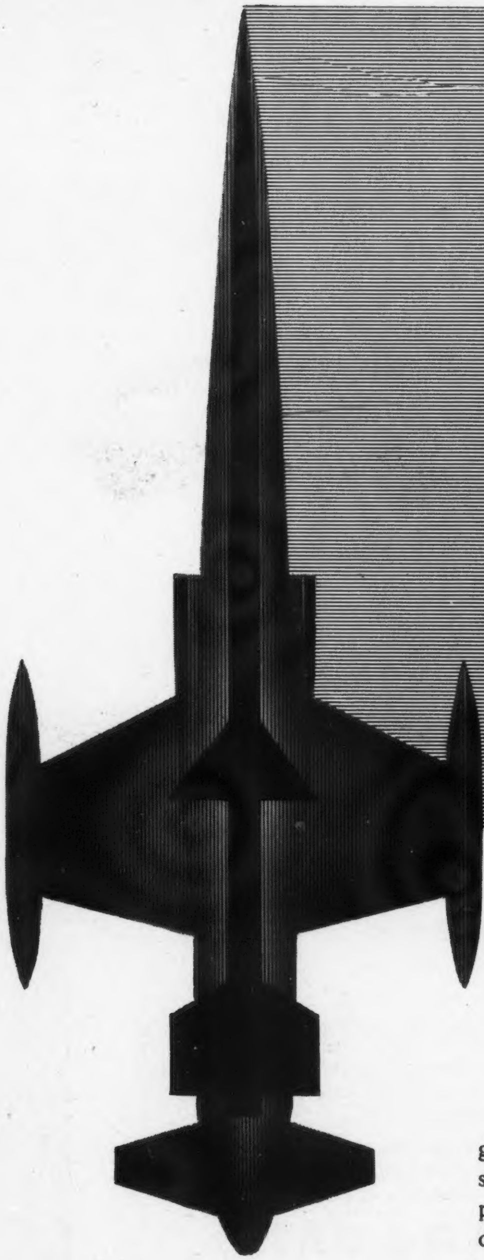

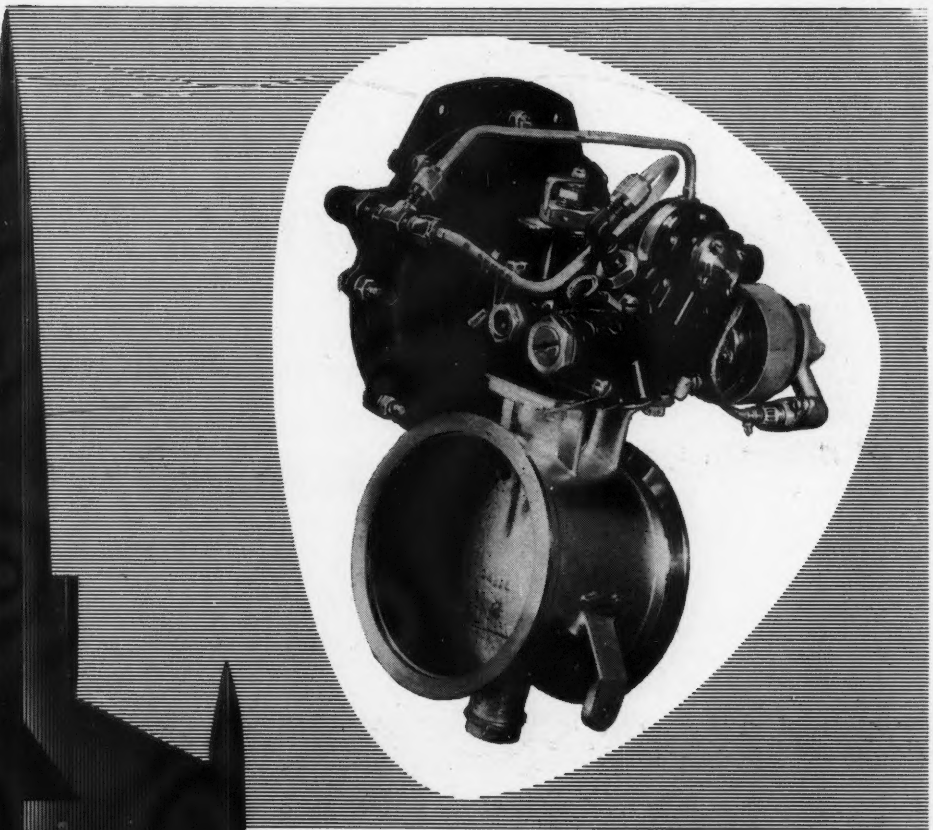

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# BURRO REPLACEMENT

**A Bell 47 helicopter of Spartan Air Services Ltd. used to take a prospector to out of the way places.**

# EDITORIAL

## AIRCRAFT MATERIALS — FACT OR FICTION

TEN years ago, a few types of fighter aircraft were assaulting the sonic barrier at a speed of Mach 1, and for their offensive armament carried missiles, which were then called 'rockets'. At the same time, very special research aircraft were attaining speeds of between Mach 1.5 and 2; they were rocket propelled and carried no armament. The first jet transport was about to fly at a projected speed of Mach 0.8.

These aircraft were built with conventional materials – 2024 and 7075 aluminum alloys, AZ31 magnesium alloy, low alloy steels up to 200,000 psi U.T.S. and a small amount of chrome-nickel heat resisting steel and Inconel X in the hot parts of the tail-pipes and shrouds.

Today we are told that the age of the military aircraft is gradually coming to a close, with the advent of a variety of missiles, and that aerodynamicists and project designers are beginning to work on schemes for jet transports which will fly as fast and faster than the research aircraft of 10 years ago. Speeds to Mach 3 have been mentioned. Already, they are talking a new language, some of it is their own and some of it is culled from the engine men. 'Kinetic heating' with skin temperatures approaching 750°F, 'heat sinks', 'thermal insulation', 'creep' and 'stress rupture'.

A Mach 2 aircraft is almost too much for 7075 aluminum alloy owing to the high depreciation in strength properties due to kinetic heating at this speed. 2024-T81 and the new lithium bearing X2020 will hold aluminum alloys in the picture to possibly 350°F for short time exposures, but this is a long way below the requirement for a very high speed transport. Thermal insulation will possibly extend the short time temperature exposure to 500°F. Thorium containing magnesium alloys, which are currently in use in some missiles, can be used for short time exposures up to 600°F, but they need special protective treatment to enable them to withstand environmental corrosion. The titanium alloys offer some hope at 750°F, especially the 6 aluminum – 4 vanadium and 7 aluminum – 3 molybdenum types, but they will be most unpopular with the production men. The heat treatable stainless steels, such as 17/7 and AM 350, have a slight edge over titanium in terms of specific properties, but are just as difficult to process – they are however cheaper in price.

A mild revolution has, however, taken place with our oldest strong alloy – steel. Low alloy steel, for certain applications, has emerged from the 200,000 psi doldrums and the newest compositions are now hitting the 300,000 psi mark. By a strange paradox, one of the most promising of these is not a new steel but an old one in a new application. There are several hot die steels which at 750°F have a U.T.S. of 160,000 psi, which is due to their high tempering temperature, over 1,000°F. As these steels, designed over 25 years ago, are tool steels for hot die work and have stood the test of time, they offer considerable promise for use at elevated temperatures. There is, of course, the problem of surface corrosion resistance, but there are possible means for achieving this. The heat-treatable stainless steels are no problem from a corrosion point of view and they may well rise to the challenge of the higher strength low alloy steels.

High speed transports of the future will follow conventional methods of construction as far as possible but the present day type of sculptured wing skin, machined from light alloy, would not be feasible with steel, with its complexity of subsequent heat treatment. Aluminum honeycomb, adhesive bonded, has proved very successful in the production of stiff structures. Brazed steel honeycomb would produce a similar type of structure, but the brazing operation on a large scale, at present, imposes almost unsurmountable difficulties and high temperature adhesives appear to be somewhat unrealistic. A sandwich type structure assembled possibly by resistance welding is a possibility.

Materials for very high speed transports, other than those mentioned above, are of course possible but not at present discernible. Beryllium, much loved by the stressmen because of its high E, may be produced and what of glass cloth laminates, how far can we push them? It is, however, true to state that future designs will depend for their performance very largely on materials and the ability of production men to process them and that some very astute compromises will have to be reached between what the designer wants, what the metallurgist can provide and what the production engineer can handle.

R. SMALLMAN-TEW
*Chief Metallurgist*
*Avro Aircraft Limited*

# THE FIRST CANADIAN AVIATOR

*(Photographs copyright Alexander Graham Bell Family courtesy of the National Geographic Society)*

**F. W. (Casey) Baldwin**
**1908**

JUST fifty years ago on 12 March 1908 Canada took to the air in the person of F. W. (Casey) Baldwin.

Casey was already famous as a rugby halfback whose exploits are still remembered on the campus of Toronto University. He had sailed before the mast on a windjammer, been a member of the crew of the Temeraire, the Canadian challenger for the Canada's Cup in 1905, and would one day be well known as a yachtsman.

On graduating from the School of Practical Science of the University of Toronto in 1906, he joined Alexander Graham Bell at Baddeck, N.S., and became one of that unique, illustrious group of five, founded, inspired and financed by Mrs. Bell, the Aerial Experiment Association, which in its brief existence made contributions to the achievement of mechanical flight out of all proportion to its size and resources.

As C. G. Grey of "The Aeroplane" put it, "In the history of effective flying they come next in precedence to the Wright brothers, if the many short flights in France are excluded".

The first powered flying machine of the Aerial Experiment Association, the "Red Wing", was designed and built in some two months and embodied several features unique at that time, including tapered wings, bow string truss, double curvature wing profile (based on Turnbull's researches), a protected cockpit for the aviator and runners for operation on ice. It was powered by an eight-cylinder air-cooled V engine with a carburetor on each cylinder which developed possibly 25 horsepower and drove direct a steel pusher propeller. The whole machine weighed less than 400 pounds.

On 12 March 1908 the machine was taken out on the ice of Lake Keuka near Hammondsport, N.Y., Casey climbed aboard, the propeller was spun and Casey signalled for the take-off.

The Red Wing, after a run over the ice of 100 to 150 feet, was seen by the many astonished and delighted spectators to lift, slowly climb and fly steadily at a height of about 10 feet for a distance of some 319 feet before buckling of a strut forced a landing but without further damage.

Thus Casey Baldwin, the first Canadian aviator, made the first public flight in a heavier-than-air machine in America. It was the longest flight yet made on the first attempt by a new machine and the first time an aircraft had operated off ice. It was a solo flight without prior training.

The imperturbable Casey, however, saw nothing spectacular in the performance. He had a cool judgment and iron nerve, had been confident Red Wing would fly and was unimpressed.

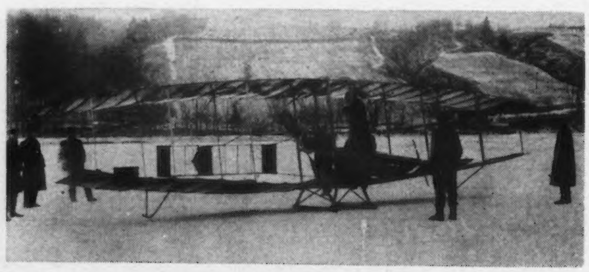
That he realized, better than the contemporary politicians of his country, the significance of man's achievement of powered flight is clear from his paper on Aviation read before some 1,100 enthusiastic students at his alma mater a year later when he said, "The usefullness of flying machines in war ensures the continuous development of the Art of Aviation. The great military powers are afraid of the flying machine and the struggle to improve it must therefore go on. Self protection demands more practical, more airworthy, and more efficient machines.

"Flight has been accomplished. The flying machine is actually here and no great Nation can afford to neglect it."

Casey lived to see his views borne out and was himself the first of the thousands of gallant Canadian aviators who proved their worth in aerial combat in two world wars and whose daring, courage and resourcefulness effected the aerial development of their country.

J. H. PARKIN
*Ottawa*

**Mr. Baldwin and the Red Wing just before the first flight. He is in the centre of the group, in a dark shirt.**



**Red Wing**
**12 March 1908**

# AEROPHYSICAL PROBLEMS OF FLIGHT AT EXTREME ALTITUDES AND SPEEDS

*Continued from Page 47**

## Part 3. EXPERIMENTAL FACILITIES AND TECHNIQUES

### HYPERSONIC FLIGHT VEHICLES

Hypersonic flight is close to reality. The conviction is growing from current research and development that difficult aerodynamic, structural and metallurgical problems can be solved[63]. Although this paper is restricted to aerophysical problems, it should be pointed out that considerable important research is being done in the structural and metallurgical fields. For example, aerodynamic heating produces many difficult structural problems even at Mach numbers as low as 2.5[64].

No single technique is available for the solution of all the aerophysical problems of hypersonic flight. Various techniques must be used and the separate results synthesized in the design of a hypersonic vehicle. Before discussing the techniques available for hypersonic research, let us consider some hypersonic rocket models which have been developed[65, 66].

A four-stage rocket vehicle has been developed by NACA for flight tests up to a Mach number of 10. In general this vehicle was designed to make use of existing rocket motors, instrumentation and materials found reliable in the supersonic range. The first and second stages are powered by M-5 JATO or Nike booster motors, the third stage by a Thiokol T-40 rocket motor and the fourth stage or test vehicle by a Thiokol T-55 rocket motor. Considerable attention was given to special locking devices and aeroelastic deformation. The standard booster fins were found to be subject to high heat transfer rates at hypersonic speeds and were replaced by a tailflare on the test vehicle. The tailflare gave the required stabilization and was subject to less severe heating effects. A telemeter unit is located in the test vehicle ahead of the rocket motor, the transmitting antenna being the metal nose cone which is electrically insulated from the remainder of the test vehicle. Accelerometers and heat transfer thermocouples are included in the installed instrumentation, and ground-based radar is used for measurements of velocity and position.

By changing the number of stages and the time delays between stages, various flight paths can be obtained, thus providing a wide range of test conditions. Information on hypersonic flight at high altitude is obtained by firing all stages during the climbing phase. Measurements at lower altitude can be made by firing the final two stages during descent.

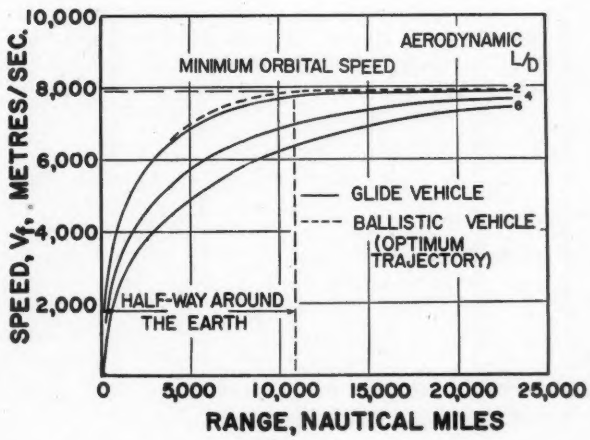



**Figure 16**
**Effect of burnout speed on range for ballistic and glide vehicles (Reference 3)**

Some idea of the design problems involved can be obtained by considering two kinds of hypersonic vehicle – the ballistic missile and the rocket-boosted hypersonic glider[3]. The ballistic missile has a flight path which is mainly outside the sensible atmosphere, only the initial and final phases being in air of any appreciable density. On the other hand the glider remains within the atmosphere at densities sufficient to provide aerodynamic lift. The speeds at burn-out which these vehicles must attain in order to reach a given range are indicated in Figure 16. It will be seen that the burn-out speeds of the ballistic missile are about the same as those of the rocket glider if the ratio of lift to drag of the latter is about 2.

At $L/D > 2$ the hypersonic glider can operate at lower speeds for the same range than can the ballistic missile and the problem of aerodynamic heating is correspondingly reduced. Clearly the achievement of large lift/drag ratios under high-altitude, high-speed conditions is an important research problem. At the higher altitudes the low air density will promote low rates of convective heat transfer and it is possible that the glider vehicle may be cooled sufficiently by radiation from its exposed surface. Calculations show that the radiation equilibrium temperature is at least an order of magnitude lower than the recovery temperature. However additional cooling would probably be required in areas where stagnation temperatures are attained.

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*CANADIAN AERONAUTICAL JOURNAL, February 1958.

The ballistic missile will encounter extremely large heat transfer rates when it re-enters the earth's atmosphere and radiation cooling will not be of much help. On the other hand if the ballistic missile is designed so that its drag is large compared with its weight and the pressure drag is large compared with the skin friction drag, then the kinetic energy of the ballistic missile will be dissipated in heating the atmosphere rather than the surface of the vehicle[67]. Direct forms of cooling also can be applied in this case.

The free flight method of research provides the correct test conditions and most of the aerodynamic and structural problems of hypersonic flight can be investigated by this method. However, details of flow configurations cannot be obtained by this method and the relative inflexibility of the experimental program, the time taken to obtain data, and the high cost of this technique make it necessary to use other kinds of test facility.

**BALLISTIC RANGES**

The full scale conditions of hypersonic flight through the atmosphere can be closely simulated by ballistic range techniques. The basic problem is to reproduce the Mach number, Reynolds number and the air and model temperatures. The correct representation of the wave system requires the correct Mach number. Investigations of the properties of the boundary layer can be done only at the appropriate Reynolds number. Stagnation temperatures must correspond with hypersonic flight if real gas effects are to be included.

The attainment of hypersonic Mach numbers in a ballistic range depends primarily on the development of high velocity guns. The latter do not ordinarily attain hypersonic launch velocities. In the past rifled and smooth bore guns of standard design using commercial gunpowder as a propellant have been satisfactory. However, limitations due to breech pressure, high rates of model acceleration, and the properties of the propellant indicate that the Mach number achieved by conventional guns will be less than about 5. The first two limitations are structural problems and the third indicates the need for an aerophysical study of other propellants which might be used.

Under normal conditions the propelling gas is accelerated from rest by a single isentropic expansion wave. For a one-dimensional, unsteady expansion, the pressure change is related to the velocity change as follows[68],

$$du = -\frac{dp}{\rho a} \tag{27}$$

The product of the speed of sound and the density ($a\rho$) is called the acoustic impedance. In order to produce a large increase in velocity for a given decrement in pressure, the propelling gas must be such that it has a low acoustic impedance. Under conditions of high temperature the gas may be assumed to be approximately ideal and for this case

$$a\rho = p\sqrt{\frac{\gamma M_w}{RT}} \tag{28}$$

Therefore the acoustic impedance will be small if the molecular weight ($M_w$) is small and the temperature ($T$) is high. Since ordinary propellants have products of combustion of high molecular weight and the temperature is limited by the chemical energy of the powder, it is evident that by using gases of low molecular weight heated by compression rather than by the addition of chemical energy, a higher launching speed can be obtained.

Guns using helium as a propellant have been developed recently[69, 70]. In one case a piston of appreciable mass is pushed along the tube at a moderate speed by exploding a charge of gunpowder. The helium is compressed isentropically. As the piston is brought to rest, maximum pressure is reached and the projectile is propelled along the launch tube by hot, compressed helium. In a second design the piston is omitted and the helium is compressed by a shock wave and heated non-isentropically to a temperature above the corresponding isentropic value. Other factors, such as a large chamber volume, large amount of propellant, low mass of projectile, large bore diameter, and a long barrel also improve the launching speed.

The effective Mach number can also be increased by firing the projectile through the test section of a supersonic wind tunnel. The Mach number is increased by raising the relative air speed and by reducing the speed of sound. The maximum Mach number of the tunnel is limited by the minimum throat area through which the projectile must pass and by air condensation if the tunnel is of conventional design. Also, very low temperatures in the test section raise problems relevant to temperature simulation. A launching Mach number of 6 in still air at room temperature combined with a tunnel Mach number of 3 gives a resultant Mach number of 13. On the other hand, although the ratio of stagnation point enthalpy to the free stream enthalpy is correct for a given Mach number, the static temperature of the undisturbed flow is somewhat below flight values. However, actual stagnation enthalpies are quite high. Full scale Reynolds numbers can be simulated by controlling the air density in the test section. Supply pressures for the wind tunnel up to 5 atmospheres are required for this purpose.

It has been indicated that the Reynolds number at which the boundary layer changes from laminar to turbulent flow is important in the calculation of aerodynamic heating effects. The study of the transition Reynolds number is an important application of the ballistic range technique. Shadowgraphs showing the wave system and details of the boundary layer for blunt nosed projectiles are readily obtainable[70, 71]. The end of the transition region is usually indicated by the appearance of small vortices near the surface of the model. In this case the Reynolds number is defined in terms of the momentum thickness of the laminar layer at the transition point. The results of such experiments indicate that below a momentum thickness Reynolds number of about 300 the laminar layer remains stable. This is a subject for further investigation.

Real gas effects can also be studied in the ballistic range. A gas having very heavy molecules has a low specific heat per unit mass, and if such a gas is mixed

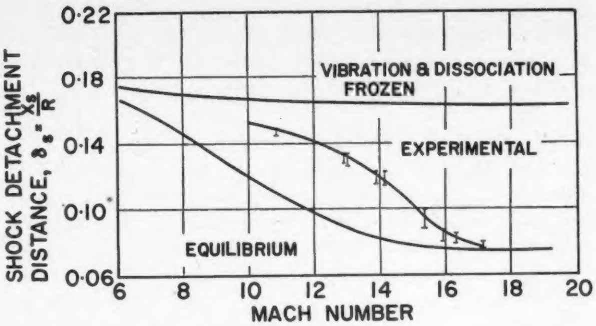


**Figure 17**
**Shock detachment distance measured for various Mach numbers in a mixture of xenon and nitrogen (Reference 69)**

with nitrogen, the resultant stagnation temperature on a projectile is much higher. A study of the effect of vibration and dissociation of the molecules on the distance between the head shock wave and a sphere has been reported in Reference 72. Spherical models were fired through a mixture of nitrogen and xenon at speeds up to 12,000 ft/sec. Schlieren pictures of the head wave in front of the sphere were sufficiently distinct to make possible the measurement of the displacement distance. The results are given in Figure 17. It will be seen that the experimental curve lies between two theoretical curves calculated on the assumption of very long and very short relaxation times relevant to vibration and dissociation, respectively, the effect of the ionization of xenon being considered negligible. These experiments indicate the effect of relaxation times on shock wave properties.

**LOW DENSITY WIND TUNNELS**

Provided the flight conditions can be satisfactorily simulated, the wind tunnel possesses advantages with respect to the convenience, scope, and detail of measurements and flexibility of the test program. We shall now consider various kinds of wind tunnel beginning with those designed for low density studies.

Up to about 1947 no experimental work had been done on the high speed flow of rarefied gases. Work then began concurrently at the Ames Aeronautical Laboratory (NACA) and the University of California on the development of low density wind tunnels. Some time later (1953), with helpful advice and encouragement from the research groups in the above two organizations, the Institute of Aerophysics, University of Toronto, undertook to develop a wind tunnel capable of operation at very low densities.

Low density tunnels now in operation are of the continuous flow, non-return, open-jet type. The test gas may be air taken from the room through a dust filter and drier or bottled gas rendered dry by passing it through a refrigerated trap at high pressure. The mass flow of inlet gas is controlled and measured. It is heated to a desired temperature and then it passes into a large settling chamber which contains a liner heated to the same temperature. The gas passes next through the nozzle forming a jet in a large test chamber in which the instrumentation may be placed. The gas then proceeds to a surge chamber connected to the vacuum pumps.

The low density tunnels developed by the Ames Aeronautical Laboratory and the University of California are described in References 73 and 74 respectively. A report on the UTIA low density wind tunnel is available[75]. In the subsonic range ($0.1 < M < 1.0$) this wind tunnel was designed for operation at pressures between 1 and 70 microns Hg., Reynolds numbers per inch from 0.08 to 70, and mean free paths between 2.0 and 0.02 inches. For supersonic operation ($1.0 < M < 5.0$) the pressure range was the same, and the Reynolds number per inch and mean free path varied from 10 to 4,000 and 0.2 to 0.002 inches, respectively.

A photograph of the UTIA low density tunnel is shown in Figure 18. The primary pumping system consists of six booster-type oil diffusion pumps having a combined pumping speed of about 7,200 liters per second over the range of operating pressures indicated above. The booster pumps are connected to two large mechanical pumps which form a second stage. Conventional axisymmetric nozzles for Mach numbers of 2 and 4 have been used. The design Mach number was achieved in the center of the jet but the core of uniform flow was limited to a relatively small region due to the large thickness of the boundary layer. In fact, measurement at pressures below about 10 microns was not practicable because the boundary layer covered the whole jet. Very large slip velocities were observed on the walls of the subsonic nozzle. Provision has been made for boundary layer suction[73]. Special instrumentation is required, such as free molecule probes and the electron gun. Figure 19 illustrates how a beam of electrons may be used to survey the density field near a flat plate placed perpendicular to the direction of flow.

The wind tunnels discussed above do not yet simulate the stagnation temperatures or Mach numbers characteristic of the range of hypersonic flight and further progress is needed in this direction. Attention is being given, therefore, to the development of a tunnel which will operate at low densities and high Mach numbers and stagnation temperatures by the expansion of a jet from a plasma generator[65].

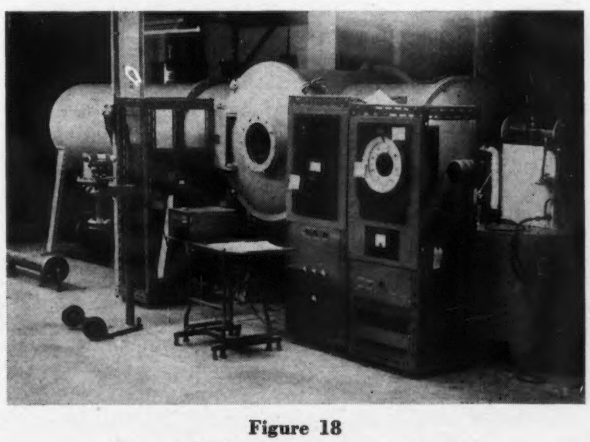

**Figure 18**
**View of UTIA low density wind tunnel**

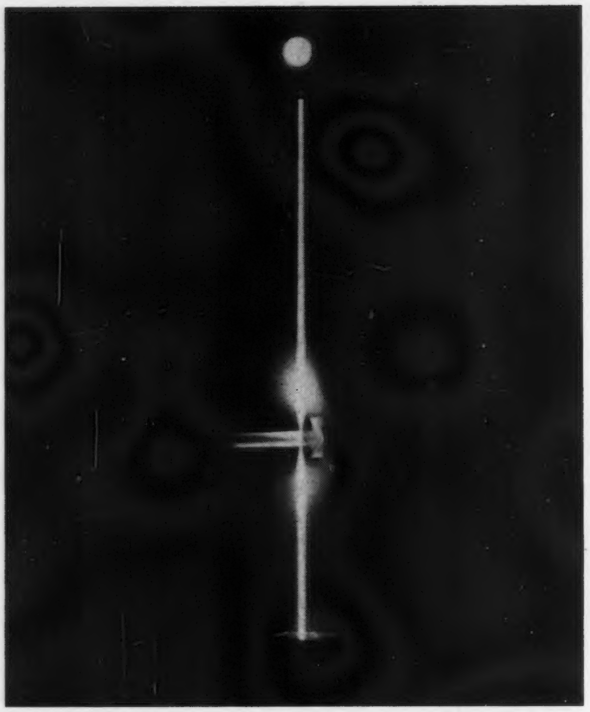

**Figure 19**
**Electron beam passing through the flow field around a blunt shape at low density**

Very high temperatures can be achieved by enclosing a high-current electrical arc in a chamber. One form of generator is outlined in Figure 20 (see Reference 65). It consists of a pressure vessel containing a graphite rod (anode) and a graphite plate with a circular hole (cathode). Air flows in around the anode, through the arc where it is heated, and out through the hole in the cathode. High temperature can be achieved without the use of high pressure by thermal and magnetohydrodynamic effects[76]. When cooling by water or gas is provided, the arc is surrounded by a fluid vessel which separates it from the walls of the chamber and cools the gases in the outer regions of the plasma. A further effect of the cooling is to reduce the ionization and therefore the conductivity of the gases in the outer regions, thus concentrating the current in the discharge in the hotter core of the plasma. The result is a "thermal pinch effect". A "magnetic pinch effect" also occurs when the current density is sufficiently high. Analogously with the attraction between two parallel conductors having currents flowing in the same direction, the charged particles are attracted to each other by their self induced magnetic fields, constricting the discharge still further.

The plasma jet attains temperatures in the range 15,000-30,000°F which are substantially above those obtainable by chemical methods. In a wind tunnel the plasma enters the nozzle at the speed of sound and is expanded to a normal temperature and high Mach number through the use of a vacuum pumping system. As the temperature drops the gas recombines, reaching equilibrium in the test section. If a model is placed in the test section, the head shock wave reproduces the very high temperatures available in the system and a plasma again appears behind the shock. A tunnel of this type is very useful for studying magnetohydrodynamic effects at extreme altitudes.

**HYPERSONIC WIND TUNNELS**

For detailed investigations of many problems in hypersonic flight it is important to have wind tunnel facilities which simulate the stagnation temperature, Mach number and Reynolds number of hypersonic flight. A relatively long running time is a further requirement. Many types of wind tunnel have been developed to meet these requirements. We shall discuss some of the more important design features.

High temperature jets have been developed for use where it is essential to reproduce the thermal conditions of hypersonic flight. Early consideration was given to hot gases produced by combustion[77, 78]. Air from a high pressure supply is preheated electrically and then led into a combustion chamber in which ethylene gas is burned using a ramjet burner. Variation in the stagnation temperature gave a range of Mach numbers between 2 and 6. The jet from a rocket motor using red fuming nitric acid and anhydrous ammonia as propellants has also been employed for test purposes. A wide range of total temperatures can be made available. Hot jets are useful for tests on materials, aerodynamic heating, and insulation and cooling of structures. However, the test gas is not air in the above two devices, which are therefore not entirely satisfactory.

Consideration has been given to methods for heating air to high temperatures of the order of 4,000°F. Since metallic heat exchangers are not suitable for such high temperatures, the use of ceramic materials was investigated. Considerable use of ceramic pebble beds as heat exchangers has been made by the petroleum and chemical industries. The early application of this method to wind tunnels was made by research groups at the University of Minnesota[79] and the Polytechnic Institute

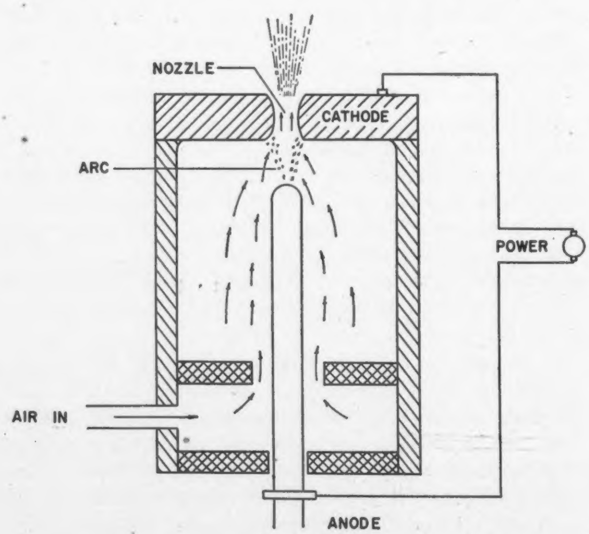


**Figure 20**
**Outline of a generator for producing a high temperature jet using an electric arc (Reference 65)**

of Brooklyn[80]. Temperatures in the range between 1,000°F and 3,000°F were produced. Extension to about 4,000°F was then undertaken by NACA and AEDC[65, 81]. A ceramic heater consists of a steel cylinder lined with ceramic blocks which forms a well in which ceramic pebbles are placed[65]. Above the well is a settling chamber and nozzle and the settling chamber is connected to an oil burner. During the heating stage fuel is burned with air and the hot gases are forced down through the pebble bed. Compressed air is then passed through the bed, settling chamber and the nozzle. Further details of heater designs may be found in Reference 81.

It will be noted that these stagnation temperatures are still not high compared with those that occur in hypersonic flight. The probable upper limit of the stagnation temperatures obtained either directly or indirectly by chemical methods is about 10,000°F. It is natural that consideration should be given to the electric arc method already described, which produces stagnation temperatures in excess of 15,000°F.

The light gas gun described above can be modified for use as a hypersonic wind tunnel of relatively short duration. The gun type tunnel was developed by NACA[82] and later by ARDE[83]. The principle of this device is illustrated in Figure 21. When the breech diaphragm is ruptured by the exploding mixture, a light piston is forced at high speed along a closed barrel, compressing the test gases in front of it. A diaphragm at the outlet section of the nozzle is designed to rupture when the piston is brought to rest in the barrel. The high pressure gas behind the piston then pushes the piston forward, ejecting the hot test gas through the nozzle at constant pressure. The test gas is heated by a series of multiple reflections. Stagnation temperatures up to 10,000°K are possible if the driver gas is a light gas like hydrogen.

The running time of this tunnel is limited by erosion in the nozzle under a high temperature. The best material for delaying the onset of erosion will be that with a high melting point, large heat capacity, and good conductivity. It is considered that running times are still sufficiently long for useful studies of heat transfer under conditions of dissociation and ionization. A tunnel of this type is also inexpensive compared with more standard designs.

In the above discussion the emphasis has been placed on the major requirement of a stagnation temperature consistent with that of hypersonic flight. In the design

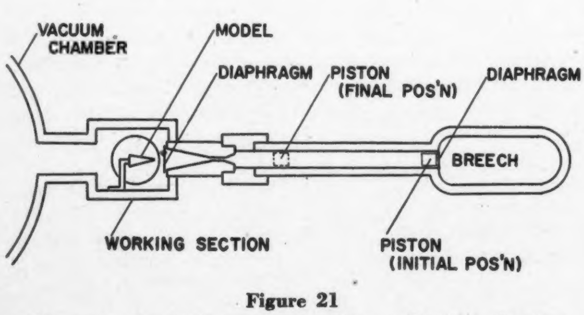


**Figure 21**
**The gun tunnel designed to utilize multiple reflection of shock waves (Reference 83)**

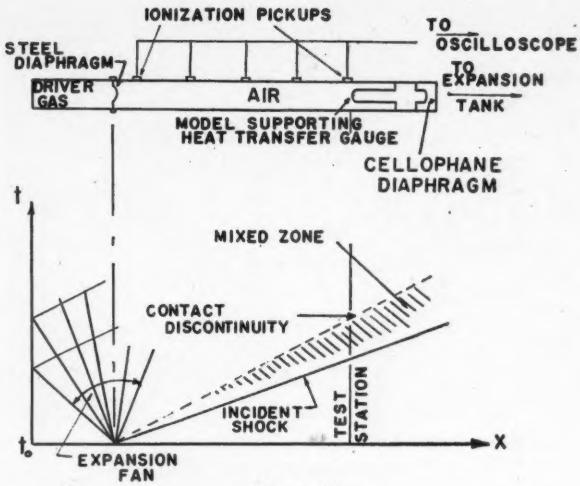


**Figure 22**
**Outline of a simple shock tube and the associated wave system (Reference 90)**

of a hypersonic wind tunnel other aerophysical problems relate to the nozzle flow. The need for cooling the walls of a nozzle has led to investigations of heat transfer rates at the nozzle throat with a view to reducing the peak value[84]. Thus a slower convergence ahead of the throat produces a lower peak heat transfer rate[81]. In order to obtain a flow in the test section free of gradients in the pressure and Mach number distributions, it is necessary to allow for the boundary layer displacement thickness. Real gas effects have been considered above.

### SHOCK TUBES

The shock tube is one of the most useful facilities for the investigation of high temperature effects. It can reproduce both the temperatures and velocities of hypersonic flight. The shock tube was originally used by Vieille in 1899 in detonation experiments. More general interest in the subject followed the work of Payman and Shepherd[85] in 1937. Since that time considerable pioneering work has been done in the United States beginning with that of Bleakney at Princeton University. Surveys of the shock tube field are given in References 86, 87, 88 and 89.

The operation of a simple shock tube can be explained with the help of Figure 22 (see Reference 90). A driver gas is separated from the test gas by a diaphragm in a long tube of constant cross-section. The driver gas may be initially cold at high pressure or the hot compressed gas resulting from the controlled combustion of oxygen and hydrogen with helium as a diluent. When the diaphragm is ruptured, the resulting wave configuration is that shown in Figure 22. A shock wave passes through the test gas at high speed and it is followed at local particle speed by a contact discontinuity across which the driver and test gases are diffusing. An expansion wave occurs in the driver gas. From the point of view of the production of strong shock waves the combustion driven shock tube has an advantage over those operated with cold helium or hydrogen.

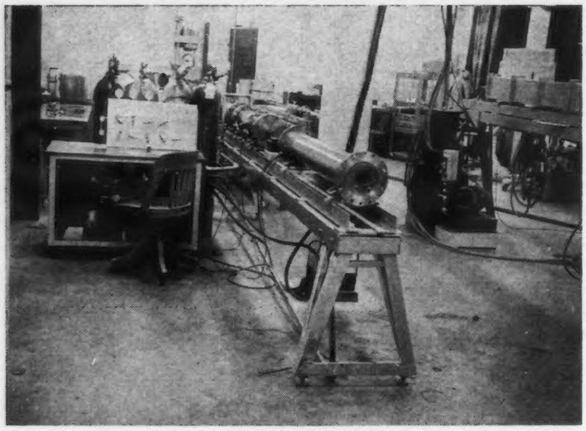

**Figure 23**
**The UTIA combustion-driven shock tube**

At the Institute of Aerophysics two shock tubes (1 in diameter and 2 in square) are in operation covering the shock Mach number range from 5 to 20 in air, argon, and nitrogen (Figure 23). The square shock tube consists of four steel plates mounted in a 6 in diameter steel pipe with a wall ⅞ in thick. The intervening space is filled with Woods metal. A total length of 24 ft is constructed in this manner with a series of ten observation ports situated at one foot intervals. The design pressure is 3,000 psi. A time-position schlieren optical system is used in conjunction with a compressed air driven drum-camera which produces film speeds up to 700 fps.

Flows at high Mach number are produced by igniting a stoichiometric mixture of hydrogen and oxygen diluted with either helium or hydrogen at initial pressures of about 150 psi. Two methods of ignition have been investigated; (a) a spark located at the closed end of the chamber containing the mixture, (b) a wire stretched lengthwise in the chamber which dissipates about 50 joules of energy. The latter method has given the best results with the least shock wave attenuation (about 0.1 Mach number per ft). The increasing pressure of the ignited mixture finally ruptures a metal diaphragm and a strong shock wave is produced.

The measured physical parameters are shock velocities, particle velocities and pressures. The shock wave velocity is determined by ionization probes and agrees with that measured from wave speed schlieren photographs to within about 1%. A contact surface which moves at particle speed is produced by passing a shock wave through a perforated disc. Its speed can be obtained from schlieren records. The pressures are measured by a diaphragm-type gauge and a piezoelectric gauge whose time responses are about 15 $\mu$ secs and 1 $\mu$ sec, respectively.

The simple shock tube is suitable for the study of high temperature effects at low Mach number. According to ideal gas theory the maximum obtainable flow Mach number is 1.89 in air ($\gamma = 1.4$). However, real gas effects result in a lower value of $\gamma$ at high temperatures and the flow Mach number can be as high as 3[91]. Measurements of vibration relaxation in a shock tube have already been mentioned.

Simulation of hypersonic flight conditions for a blunt body is possible in the simple shock tube since the correct enthalpy and pressure can be obtained. The study of the heat transfer through a laminar boundary layer near the stagnation point is important since the most severe heating occurs here and it is possible to include non-equilibrium gas effects in associated theoretical studies[92]. In shock tube tests on a blunt body[90] the Newtonian pressure distribution was obtained from measurements on Mach lines originating at the body.

The simple shock tube has other special uses. It has been used to measure the radiative emissivity of high temperature air by making a study of the radiation from a sample of gas heated and compressed by the reflection of a shock wave from the end of the tube[93]. A study of the electrical conductivity of thermally ionized air has also been made by a method based on the displacement of the lines of force of an axisymmetric magnetic field by a shock heated gas[94]. The electrical conductivity is determined from the known gas velocity and the strength, geometry and displacement of the magnetic field. Preliminary work has also been done in the simple shock tube in the field of magnetogasdynamics which is rapidly becoming important in aerodynamics. The interaction of magnetic fields with the flow of electrically conducting gases introduces body forces without the need to use solid surfaces and opens up a whole new field of aerodynamics. The purpose of these early experiments is to check the one-dimensional flow equations[95].

The simple shock tube can be combined with a nozzle to produce simulation of hypersonic flow up to satellite Mach numbers. The compressed flow at high temperature behind the shock front can be expanded to the required test section Mach number and temperature. An outline of a shock tube nozzle arrangement is shown in Figure 24[91]. A secondary diaphragm is used to reduce disturbances produced by the primary wave as it passes through the nozzle. These disturbances tend to move upstream and reduce the available testing time. The testing time can be further increased by expanding the flow in the shortest possible distance.

The hypersonic shock tunnel shows good promise but many problems remain to be investigated. The most severe limitation is the testing time. For example, the testing time at $M = 15$ is only about half a millisecond. However, there is theoretical and experimental evidence to show that the flow over models is fully established during this brief testing time although some doubt exists regarding wake flows. The required instrumentation must have a very rapid response time. Resistance thermometers have been successfully developed for the measurement of heat transfer. Techniques for pressure measurement are under consideration. Special kinds of pressure transducers are needed especially for low pres-

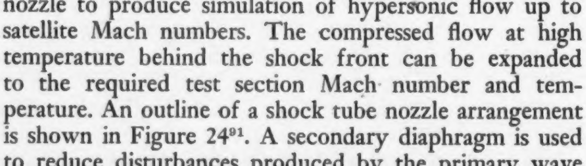


**Figure 24**
**One form of hypersonic shock tunnel (Reference 91)**

sures. Present information indicates that balance systems can be constructed which will provide force measurements in the short testing time. Another problem under investigation is the shock attenuation due to viscous forces[96, 97, 98]. The shock tube must have a large length-to-diameter ratio (e.g. 250) in order to keep the testing time as long as possible. Over such lengths shock attenuation can become appreciable. The need for longer testing times and for a solution of the attenuation problem has led to the development of the "reflected shock tube"[91]. In this design the nozzle is the standard converging-diverging type. The primary shock wave is now nearly completely reflected since the area of the nozzle throat for hypersonic flow is so small. The hot, compressed, stationary air left at the end of the tube then expands through the hypersonic nozzle. This design is expected to improve the testing time by an order of magnitude.

## REFERENCES


(63) Jeffs, G. W. – *Selecting an Advanced Weapons System*, SAE Jour., p 17, March, 1957.

(64) Dryden, H. L., and Duberg, J. E. – *Aeroelastic Effects of Aerodynamic Heating*, Proc. Fifth AGARD General Assembly (Canada), p 102, June 15-16, 1955.

(65) Purser, P. E., and Bond, A. C. – *NACA Hypersonic Rocket and High-Temperature Jet Facilities*, presented to AGARD meeting, Scheveningen, Holland, July 8-12, 1957.

(66) Shortal, J. A. – *Techniques of Model Tests in Free Flight*, Proc. Fourth AGARD General Assembly (Netherlands) p 56, May 3-7, 1954.

(67) Allen, H. J., and Eggers, A. J. Jr., – *A Study of the Motion and Aerodynamic Heating of Missiles Entering the Earth's Atmosphere at High Supersonic Speeds*, NACA RM A53D28, 1953.

(68) Slawsky, Z. I., Michells, A., and Jacobs, S. J. – *The Rapid Expansion of Compressed Gases Behind a Piston*, Physica, Vol. 20, p 220, The Hague, 1954.

(69) Thurston, P. A. – *Research in the NOL Ballistics Range*, presented to AGARD meeting, Scheveningen, Holland, July 8-12, 1957.

(70) Seiff, A. — *The Use of Gun-Launched Models for Experimental Research at Hypersonic Speeds*, Presented to AGARD Meeting, Scheveningen, Holland, July 8-12, 1957.

(71) Witt, W. R., and Persh, J. – *A Correlation of Free-Flight Transition Measurements on Various Blunt Nose Shapes by Use of the Momentum-Thickness Reynolds Number*, NAVORD Report 4400, U.S. Naval Ordnance Laboratory, December, 1956.

(72) Schwartz, R. N., and Eckerman, J. – *Shock Location in Front of a Sphere as a Measure of Real Gas Effects*, J. Appl. Phys. Vol. 27, p 169, February 1956.

(73) Stalder, J. R., Goodwin, G., and Creager, M. – *A Comparison of Theory and Experiment for High-Speed Free-Molecule Flow*, NACA Report No. 1032, 1951.

(74) Schaaf, S. A., Horning, D. O., and Kane, E. D. – *Design and Initial Operation of a Low Density Supersonic Wind Tunnel*, Institute of Engineering Research, University of California, Report No. HE-150-62, 1949.

(75) Enkenhus, K. R. – *Design of UTIA Low-Density Wind Tunnel*, UTIA Report No. 44, 1957.

(76) Giannini, G. M. – *The Plasma Jet*, Scientific American, p 80, August, 1957.

(77) Faget, M. A., Watson, R. S., and Bartlett, W. A. Jr. – *Free-Jet Tests of a 6.5 inch-Diameter Ram-Jet Engine at Mach numbers of 1.81 and 2.00*, NACA RM L50L06, 1951.

(78) Duberg, J. E. — *Aircraft Structures Research at Elevated Temperatures*, presented to second meeting of Structures and Materials Panel of AGARD, England. Sept. 5-9, 1955.

(79) Hermann, R., Leitinger, H., and Melnik, W. L. – *Research on the Design of Hypersonic Nozzles and Diffusers at High Stagnation Temperatures; Part I, Design and Construction Problems of a Hypersonic Facility and Preliminary Investigations of Liquid-Film Cooling*, WADC TN 55-507, Wright Air Development Center, U.S. Air Force, March, 1955.

(80) Ferri, A., Libby, P. A., Bloom, M. H., and Zakkay, V. – *Development of the Polytechnic Institute of Brooklyn Hypersonic Facility – An Interim Report for the Period 15 January, 1952 to 31st July, 1955*, WADC TN 55-695, Wright Air Development Center, U.S. Air Force, Nov. 1955.

(81) Smelt, R., and Sivells, J. C. – *Design and Operation of Hypersonic Wind Tunnels*, Presented to AGARD Meeting, Scheveningen, Holland, July 8-12, 1957.

(82) Stalder, J. R., and Seiff, A. – *The Simulation and Measurement of Aerodynamic Heating at Supersonic and Hypersonic Mach numbers*, presented to seventh meeting of Wind Tunnel and Model Testing Panel, AGARD, June, 1955.

(83) Cox, R. N., and Winter, D. F. T. – *The Light Gas Hypersonic Gun Tunnel at ARDE, Fort Halstead*, presented to AGARD meeting, Scheveningen, Holland, July 8-12, 1957.

(84) Libby, P. A., and Napolitano, L. G. – *A Theoretical Investigation of Some Boundary Layer and Heat Transfer Problems Connected with Hypersonic Wind Tunnel Nozzles*, AEDC TR-55-51, July, 1955.

(85) Payman, W., and Shepherd, W. C. F. – *Explosion Waves and Shock Waves*, Proc. Roy. Soc. London (A) Vol. 158, p 348, 1937, Vol. 186, p 293, 1946.

(86) Bleakney, W., and Taub, A. H. – *Interaction of Shock Waves*, Rev. Mod. Phys., Vol. 21, p 584, 1949.

(87) Glass, I. I., and Patterson, G. N. – *A Theoretical and Experimental Study of Shock Tube Flows*, J. Aeronaut. Sci., Vol. 22, No. 2, p 73, 1955.

(88) Penney, W. G., and Pike, H. H. M. – *Shock Waves and Propagation of Finite Pulses in Fluids*, Reports of Phys. Soc. on Prog. Phys., Vol. 13, p 46, 1950.

(89) Hertzberg, A. – *The Application of the Shock Tube to the Study of High Temperature Phenomena in Gases*, Applied Mechanics Reviews, Vol. 9, No. 12, p 505, 1956.

(90) Rose, P. H. – *Physical Gas Dynamics Research at the AVCO Research Laboratory*, presented at AGARD meeting, Scheveningen, Holland, July 8-12, 1957.

(91) Hertzberg, A. – *The Shock Tunnel and its Applications to Hypersonic Flight*, presented at AGARD meeting, Scheveningen, Holland, July 8-12, 1957.

(92) Fay, J. A., and Riddell, F. R. – *Theory of Stagnation Point Heat Transfer in Dissociated Air*, AVCO Research Laboratory, Research Note 18, Revised, April 1957.

(93) Keck, J. C., Kivel, B., and Wentink, T. Jr. – *Emissivity of High Temperature Air*, AVCO Research Laboratory, Research Note 33, April 1957.

(94) Lin, S. C. – *Electrical Conductivity of Thermally Ionized Air Produced in a Shock Tube*, AVCO Research Laboratory, Research Note 26, Feb. 1957 (J. Appl. Phys., July, 1957).

(95) Patrick, R. M., and Brogan, T. – *One-Dimensional Flow of an Ionized Gas Through a Magnetic Field*, AVCO Research Laboratory, Research Note 36 (to be published).

(96) Trimpi, R. L., and Cohen, N. B. – *A Theory Predicting the Flow of Real Gases in Shock Tubes with Experimental Verification*, NACA TN 3375, March, 1955.

(97) Mirels, H. – *Attenuation in a Shock Tube Due to Unsteady Boundary Layer Action*, NACA TN 3278, August 1956.

(98) Martin, W. A. – *An Experimental Study of the Boundary Layer Behind a Moving Plane Shock Wave*, UTIA Report No. 47, October, 1957.

# FLYING THE JET STREAM†

**by P. R. J. Reynolds* and C. L. Chandler****

***Pan American World Airways***

The major air traffic routes between North America and the United Kingdom-Continent fall between the fortieth and sixtieth parallels of north latitude and it is also between these parallels that the North Atlantic polar jet stream is most often found. Nearly all the North Atlantic commercial air carriers utilize some form of pressure pattern technique in flight planning, and as the jet stream embodies the maximum winds in the area it is naturally of great importance in track selection.

The jet stream consists of a localized acceleration of airflow along a surface of discontinuity (frontal surface) between the levels of approximately 10-12,000 ft and the tropopause. Jet stream wind velocities as high as 400 kts have been determined by radiosonde and radar wind observations, but the average of jet stream core velocities is more of the order of 180-200 kts. The term "jet stream" is more properly defined as a velocity reaction associated with frontal action rather than as a wind velocity in excess of some arbitrary value, such as 70 or 100 kts.

### GENESIS OF THE JET STREAM

The polar regions of the earth are overlaid with a blanket of cold dense air; this blanket covering a larger area, and being colder during winter than during summer months. The intense cooling of the lower levels of the polar air produces a general subsidence and high atmospheric pressures. Large masses of polar air, generally referred to as polar outbreaks, drive well down into the middle latitudes, even into the tropics during the winter. The action of these polar outbreaks has much to do with the formation of jet streams.

The atmosphere of the temperate or middle latitudes is characterized by a general east-to-west flow of relatively warm air – meteorologists refer to it as "tropical air" in order to distinguish it from the polar air of the above paragraph, and the general public refer to it as the "prevailing westerlies" of the middle latitudes.

The surface along which the polar and tropical air masses are in contact, i.e. the southern boundary of the polar air or the northern boundary of the warm air (as you will), is termed the "polar front". In the horizontal plane, this frontal surface may be traced all the way around the world, bulging southward and sharply defined thermally in the region of a polar outbreak – weak and difficult of location in a static region. In the vertical plane it is a sloping surface, due to the cold polar air under-running the warm air, extending from the surface to the tropopause.

The contrasting thermal properties and mechanical interaction of these two air masses, which are in contact along the polar front, result in the formation of vortices or "waves", which develop into the extra-tropical cyclones or "Lows" of the middle latitudes which travel along the frontal surface in a generally easterly direction. These "Lows" are of particular interest with respect to jet streams because they frequently trigger polar outbreaks.

### ANATOMY OF THE JET STREAM

The prevailing westerlies of the middle latitudes constitute a veritable river of warm air flowing around the world from west to east, with the polar front forming the northern bank of this river. In a region where the polar air rushes down into the warm air river, we have a squeezing (convergence) effect and marked thermal discontinuity (shear); the result is the acceleration of the warm air in the region of the frontal surface which is known as the jet stream.

Figure 1 is an actual isobaric chart for the 500 mb level (standard height 18,281 ft) over the North Atlantic area and illustrates a typical jet stream situation for this region. The long solid curves are pressure-height contours which give the height of the 500 mb level at 200-ft intervals. The line of heavy arrows, which approximates the fiftieth parallel, represents the frontal surface at the 500 mb level and its attendant wind maximum or jet stream. The position of the surface front has also been drawn to illustrate the sloping nature of the frontal surface; note that in the eastern portion, where the polar air is pushing to the southeast, the frontal slope is much steeper and the jet flow much stronger than in the western portion.

The dashed line, just to the south of the heavy arrows, which is broken at intervals by wind symbols and numerical data is the track and hourly position reports of PAA's daily flight from New York to London (PA 100). The wind arrows fly downwind and each barb thereon represents 10 kts of wind velocity, each solid diamond represents 50 kts, e.g. a solid diamond followed by four barbs represents a reported wind

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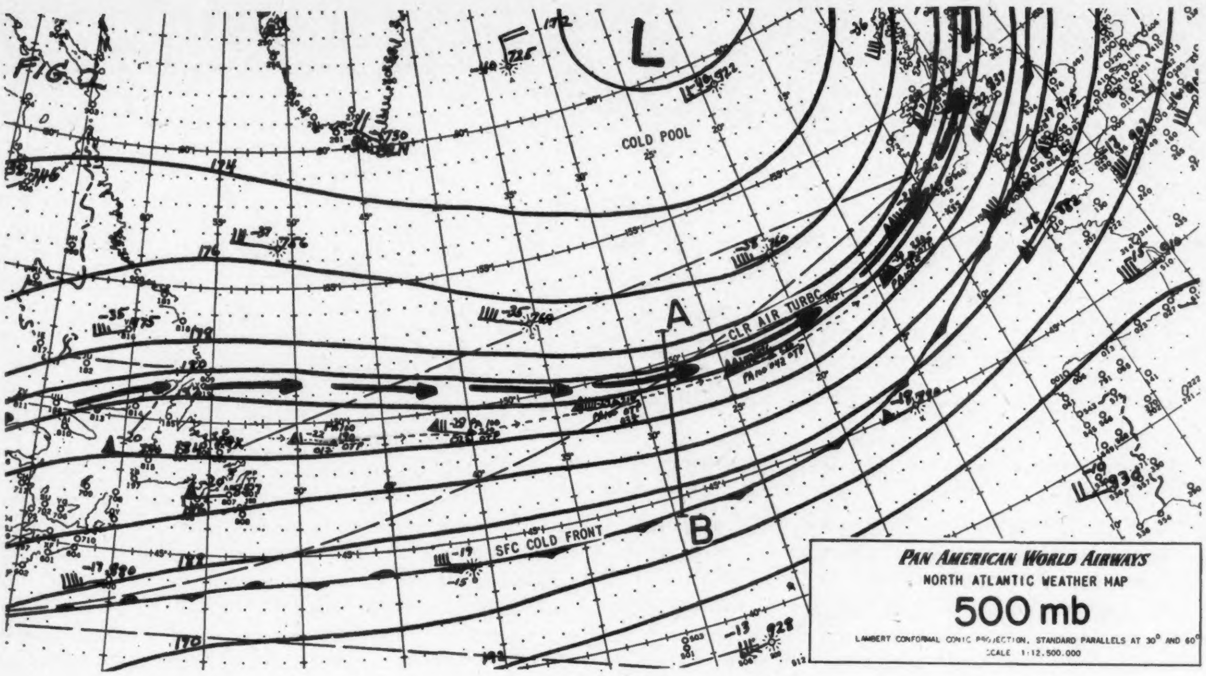


**Figure 1**

velocity of 90 kts. The notation 190 signifies a flight level of 19,000 ft; 210, 21,000 ft etc.; –22 signifies a flight level free air temperature of –22°C; 03Z signifies the time of the respective report – 0300 GMT, and OTP signifies the flight condition – on top of cloud.

In the pressure distribution depicted, a large mass of cold polar air covers the North Atlantic area to as far south as the forty-fourth parallel on the surface, sloping back up to the fiftieth parallel at the 500 mb level. Figure 2 is a transverse vertical cross section of the frontal structure taken along the line A-B in Figure 1.

The thermal discontinuity across the frontal surface may be seen by reducing one or two of the aircraft's reported temperatures to the 500 mb level and comparing them with the 500 mb temperatures reported by weather ships Coca and Juliett; for example, at 0200 GMT, Clipper 100 reported a temperature of –28°C at 21,000 ft, which reduces to –22°C at 500 mb (18,281 ft standard); weather ship Coca just northward reports a 500 mb temperature of –35°C or 13°C colder than at the aircraft's position.

The winds reported by the aircraft show up the jet flow very clearly; the flight was probably 100 mi or more south of the maximum flow in the Newfoundland area but gradually converged with the jet stream as it proceeded eastward, reporting a maximum wind of 150 kts in the region of longitude 15° West.

Note the relatively very low wind velocities in the cold polar air – 30 kts over weather ship Bravo, 40 over Coca, and 45 over Juliett; this is a typical situation and is of primary significance both in flight planning and in inflight jet stream tactics.

Figure 2 is, as mentioned above, a transverse vertical cross section of the frontal structure along the line A-B in Figure 1. The observer is assumed to be looking downstream or to the east. Isotachs are drawn for 25 kt values of wind speed and isotherms are shown as dashed lines at a variable interval. ZOMCOT is a specialized term for what we have referred to heretofore as the frontal surface; it translates as "Zone of Maximum Concentration of Temperatures". Note the sharp break in the height of the tropopause at the frontal surface. Note also that the frontal cloud structure is well southward of the jet stream with perhaps a few cirrus streamers extending northward at high altitudes.

A particularly violent polar outbreak may produce jet flow at levels as low as 4 to 6,000 ft, but ordinarily it is not found below 10 to 12,000 ft, the reason for this being that a necessary condition for clearly developed jet flow is that the thermal and pressure patterns along the frontal area be nearly identical in form and position or, in weather map terms, that the isotherms and isobars be in phase. This condition is comparatively rarely met with below the 10,000 ft level.

The average height of the jet stream core is 30 to 35,000 ft, but in cases of an unusually low tropopause, such as are encountered from time to time during the winter months, the core will be proportionately lower as well – as low as 20 to 25,000 ft in an occasional instance.

It will be seen in Figure 2 that the horizontal wind shear in the jet stream is very much greater to the left of the core, i.e. on the polar side, than it is to the right of the core; in actual fact it may be approximately ten times as great, perhaps a knot per mile on the polar side versus a knot in ten miles on the warm air side.

The vertical wind shear in the jet stream will be on the order of 10-15 kts per thousand feet below the core

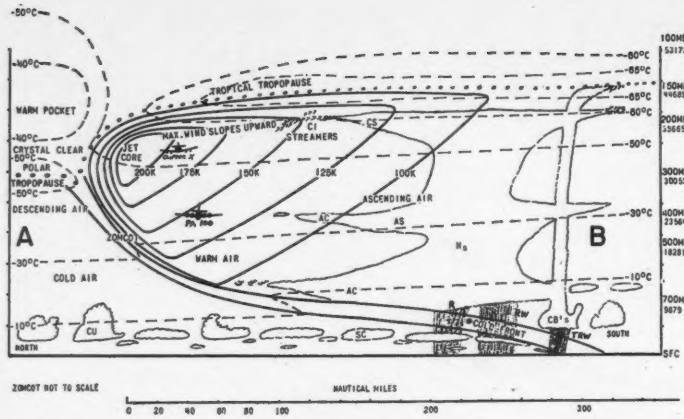


**Figure 2**
**Vertical cross section polar jet, looking downwind**

but, due to the abrupt reversal of the vertical temperature trend at the tropopause, it may reach 30 to 40 kts per thousand feet above the core.

The pronounced wind shears associated with the jet stream produce a distinctive form of atmospheric turbulence, termed "clear air" turbulence to distinguish it from normal turbulence having to do with cloud development, which varies in intensity from a slight ripple to possibly heavy turbulence at the tropopause above the jet stream core. The incidence of clear air turbulence is a useful inflight clue to the presence of the jet stream and is normally met with on the cold air side of the frontal surface.

In visualizing the jet stream's transverse structure with the aid of a model, such as that shown in Figure 2, one would be well advised to bear in mind that the model uses feet in the vertical and miles in the horizontal and that in reality the jet stream is a horizontal ribbon of air about 200 mi wide, but only about 4 mi thick.

**JET STREAM TYPES**

We have spoken hitherto as if there were but one polar front and one jet stream associated with it; in actuality, however, several more or less parallel frontal surfaces, each with its respective jet stream, may be found in the North Atlantic area at the same time. There is no standard system of nomenclature for these fronts and jet streams but we have used the terms "sub-tropical", "polar", "sub-arctic" and "arctic" to identify them; some forecasters use the 500 mb cold air temperature at the frontal surface as a means of identification also, the above four fronts being referred to as the –14°C, –20°C, –30°C and the –40°C fronts, respectively.

The four jet streams are all of the same general structure, distribution of shear etc. Figure 3 provides transverse vertical cross sections of each of the four jets as they would appear during the North Atlantic in winter. As in Figure 2, the observer is looking downstream, north is to the left etc.

The polar and sub-arctic jet streams may be found flowing parallel to each other nearly every day during the winter months and, under extreme conditions of polar outbreaks following each other in rapid succession, all four jet streams may be simultaneously present, parallel and 3 to 700 mi apart.

The sub-tropical jet stream, Figure 3(a), is associated with the southernmost penetration of polar outbreaks. During the winter months, the surface position of this front will be between the fifteenth and twentieth parallels of north latitude and it may be so weak at the surface that it is completely dropped from the weather maps. The jet core in this situation is usually found between the twenty-second and twenty-fifth parallels; surface dew points in the cold air north of the front are usually in the sixties, while they are in the mid-seventies south of the surface front.

During the summer months, the sub-tropical front moves north and becomes the active weather-producing surface front in the United States, whereas, during the winter months, the polar jet surface front is the active weather-producer in this area. In mid-summer, the sub-tropical jet stream may be located as far north as the fiftieth parallel. Much use was made of this jet stream by PAA's Atlantic Division during the summer just past. Winds of 70 to 90 kts were commonly found at the 20 to 25,000 ft level. This, the sub-tropical jet stream, is the only jet stream commonly having any appreciable amount of en route weather associated with it. This usually occurs as layered cloud – alto-cumulus and alto-stratus layers between 12 and 18,000 ft, with layered cirrus between 30 and 35,000 ft. The common sky condition reported by aircraft flying this jet stream is "between layers". Cumulo-nimbus buildups are frequently found over and northward of the surface front. As may be seen in Figure 3, the jet stream core is located at about 40,000 ft with a mean wind on the order of 100 kts. Typical temperatures and DOG values at various levels in the cold and warm air may also be seen in Figure 3.

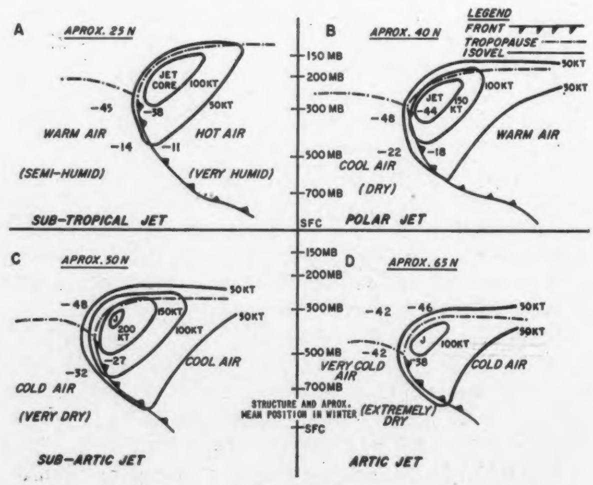


**Figure 3**

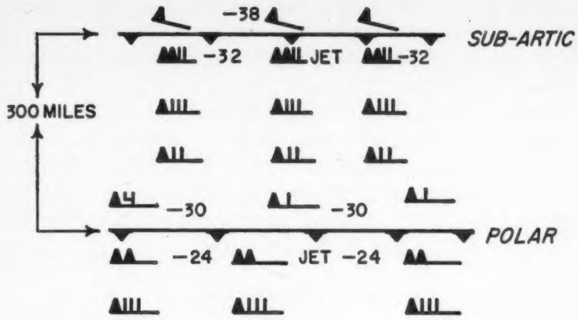


**Figure 4(a)**

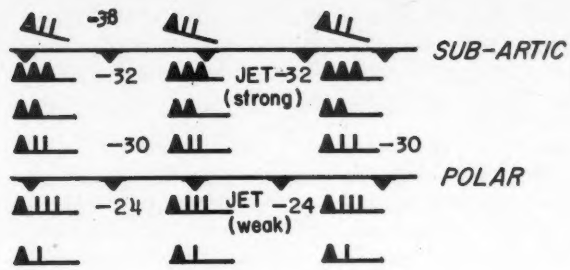


**Figure 4(b)**

**Double barrel jets (21,000 ft)**

The polar jet is present the year around, but attains its greatest development during the winter months. One might call it the "standard atmosphere jet" as it is usually found near standard conditions of temperature and pressure. During the winter months, its mean position approximates the fortieth parallel and, during the summer months, it retreats to near the sixtieth parallel.

Clear skies are ordinarily found above 15,000 ft in the polar jet stream with cirrus streamers, so-called "jet stream cirrus", occasionally appearing a short distance south of the core at the 35 to 38,000 ft level. The mean core velocity in the polar jet stream during the winter approximates 140 to 150 kts.

The sub-arctic jet stream is the strongest of all the North Atlantic jet streams. It rarely occurs during the summer months, but is usually present during the winter, its mean position approximating the fiftieth parallel. The core is found near 30,000 ft, with a mean wind velocity of 175 to 200 kts with extreme speeds up to 250 kts for short distances. This jet stream seems ideally situated for an eastbound turbine operation during the winter.

In the sub-arctic jet stream the skies are crystal clear above 15,000 ft due to the very dry air aloft. Moderate to heavy clear air turbulence is often found in the upper front and tropopause structure along the northern edge of the jet stream; this is in contrast to the other three jet stream types which usually produce only light to moderate clear air turbulence.

Aircraft of PAA's Atlantic Division make much use of the sub-arctic jet stream during the winter months, with winds of 150 to 200 kts being frequently reported between 21 and 25,000 ft; nearly all of PAA's record eastbound flights have involved the use of this jet stream.

The arctic jet stream appears only during the winter and is usually of the so-called "low index" type (short wave length — large amplitude). The mean core velocity is approximately 100 kts at an altitude of approximately 22,000 ft. This is the only jet stream type that piston aircraft may possibly climb out of; we have a number of cases on record where aircraft have penetrated the tropopause and encountered the stratospheric temperature reversal in this type of jet stream. The sky is crystal clear in the jet stream and above in the arctic jet stream.

Quite frequently a condition of so-called "double-barrelled jets" may exist where two jet streams are in phase with each other and are separated by only a few hundred miles. The two streams may well be of about equal strength when they are 300 to 500 mi apart, but when they approach closer than this, the more northern stream usually becomes the stronger, the southern stream all but disappearing when they approach within 200 mi, as may be seen in Figures 4(a) and (b).

The sub-arctic and polar jet streams are predominant over the North Atlantic area during the winter months, with the polar and sub-tropical jet streams taking over during the summer.

**THE JET STREAM IN FLIGHT PLANNING**

Prior to the now very general use of pressure pattern techniques, trans-Atlantic aircraft flew fixed tracks, such as the great circle or rhumb line, on nearly all occasions. The existing pressure pattern, therefore, had no bearing whatsoever on track selection and it made little difference whether the forecaster made a general or a finely detailed analysis of the upper air structure, since on a long flight the net result of the detailed analysis, expressed in effect on overall flight time, would be equal to that of the general analysis.

However, the fact that the weight of fuel consumed in about four minutes' time is equal to the weight of one passenger and his baggage has converted nearly all operators to a minimum flight time policy and the selection of the least time or maximum payload track has become standard operating procedure.

The actual form taken by the least time track on an upper air weather map is dependent upon three factors: (a) the true airspeed of the aircraft, (b) the overall distance to be flown and (c) the existing pressure pattern. The first two values are fixed and known in a given case, but in an area of prevalent jet stream activity, such as the North Atlantic, a finely detailed analysis of the pressure and thermal structure is absolutely essential to accurate location of the least time track, while a general area analysis may at the best be of little use, and at the worst be dangerous in the sense that it tends to show much stronger components in the cold air than actually exist, thereby displacing the least time track to the northward (in an eastbound situation) and yielding an actual flight time markedly longer than forecast.

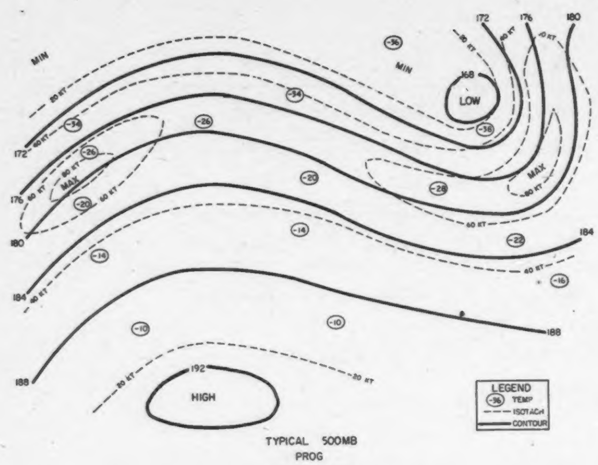


**Figure 5**
**Typical 500 mb prog**

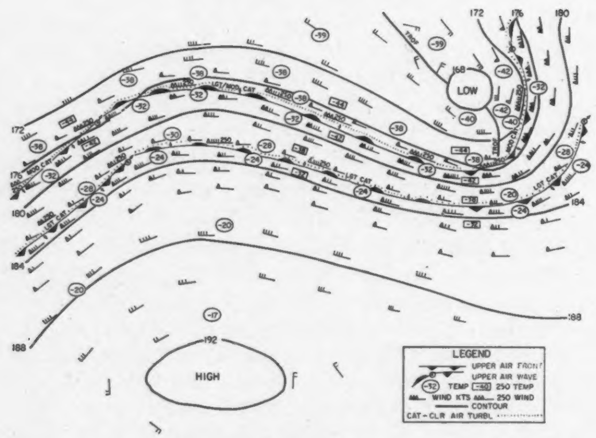


**Figure 6**
**PAA jet stream prog (ATL Div) — step climb 21,000 ft plus 25,000 ft jet winds and temps**

Figures 5 and 6 provide a comparative example of general area and detailed forecasting. Both prognostic charts have been constructed from the same set of synoptic data; (a) is a generalized area prognostic chart for the 500 mb level of the type issued by most meteorological offices, and (b) is a specialized prognostic chart showing detailed wind, pressure and temperature indications for staged levels up to 21,000 ft in the western portion (due to the aircraft's staged or step climb) and with 25,000 ft information also shown in the event that the flight may wish to consider climbing to this altitude.

Note how the generalized forecast completely conceals the jet flow along the dual frontal surface which is clearly shown in the detailed layout. It is obvious that the detailed prog is a far more useful tool to the flight planner and to the flight crew than is the generalized chart.

There are several methods of locating the least time track, but it is not felt that investigation of these techniques would be strictly relevant to this paper; suffice it to say that the track obtained is that which may be traversed in the least possible time through the predicted pressure pattern.

Once the least time track has been plotted, the forecaster/dispatcher team may wish to modify it slightly in order to minimize the effect of possible forecast error. Such modifications may include moving the track deeper into the warm air to provide for possible unexpected movement of the front etc.

**JET STREAM INFLIGHT TECHNIQUES**

When all or a substantial part of the track of a North Atlantic flight lies along a jet stream, it becomes essential that the flight actually locate and follow the jet stream; if it is unsuccessful in doing so, an economically undesirable en route fuel stop is a very likely penalty.

Even though the jet stream is shown on the prog chart to the best of the forecaster's ability, it is of such relatively narrow width and its shape is so continually changing that it devolves upon the flight crew to ensure that the flight actually locates and maintains the jet stream. Conversely, a westbound flight may accidentally find itself in a jet stream and it becomes imperative that it get out of this situation as soon as possible. Therefore, from the inflight viewpoint, jet stream tactics may be grouped under the headings of interception, maintenance or evasion.

**INTERCEPTION**

Interception of the jet stream may be accomplished in either or both of two ways, (a) vertical interception or climbing and (b) horizontal interception or convergence with the stream at a given level.

Vertical interception or climbing into the stream is of the first order of importance. It can be said, with reference to present commercial aircraft which cannot possibly climb above core level, that the first rule of jet stream interception is "get as high as you can, as fast as you can" — that is, climb to the highest level permitted by the aircraft's climbing capabilities and the air traffic controller as soon as you can. Figure 7 provides an example where the aircraft may intercept the jet stream by climbing 3,000 ft or by making a lateral interception of fifty miles.

Horizontal interception, or "taking a cut at it" in the vernacular, may possibly yield excellent results, but in all cases it is first necessary to consider all the relevant factors, such as the degree of confidence in successful interception, the predicted orientation of the jet stream with regard to the flight-planned track, the angle of interception, i.e. the angular diversion from track, obtaining air traffic control clearance for the deviation from track.

Assuming that one has reached level flight, found that one is not in the jet stream but decided that an attempt at horizontal interception is warranted, there are three points which must be decided upon: (1) one's position with respect to the frontal surface, i.e. in the cold or the warm air, which will determine whether to turn left or right; (2) the angular amount of the cut to be made and (3) the maximum period of time to be spent in attempting interception.

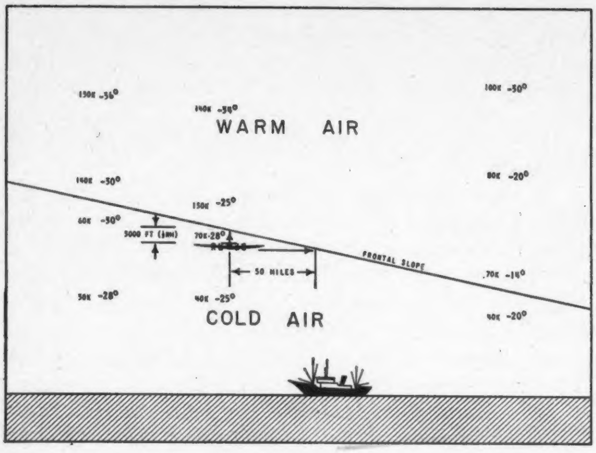


**Figure 7**
**Looking downstream — not to scale**

Plotting the aircraft's position on the weather map will indicate which side of the front the aircraft is predicted to be on, but this should not be accepted as conclusive in itself unless corroborated by inflight information. If within the recent past the free air temperature has changed several degrees in about as many minutes, there is no problem as one has just punctured the frontal surface and either just left or just entered the jet stream.

Barring the fortunate situation mentioned above, one must use less obvious clues; next best is perhaps to compare the existing free air temperature with that predicted, which may resolve the question easily, particularly if a well developed thermal shear exists across the front.

The incidence of clear air turbulence is another excellent clue, if present, to one's proximity to the jet stream. The clear air turbulence is found in the cold air along the frontal surface and its presence implies that you may intercept the stream most quickly by climbing and probably less quickly by making a lateral deviation toward the warm air. At conventional flight levels, i.e. below 25,000 ft, you are most probably just under the frontal slope when you encounter clear air turbulence.

Generally speaking, the cold air is subsiding and the warm air rising in the region of the jet stream; the incidence of subsiding air makes itself felt to the pilot in poor airspeed performance, particularly in the early stages of a flight when the aircraft is heavy, and may be a clue also.

The presence of elongated cirrus streamers, jet stream cirrus, frequently provide an excellent visual clue to the stream's location, but it must be borne in mind that they are ordinarily located well to the south of the core. Any cloud, particularly any cloud of vertical development, is far more likely to be found in the warm, moist air than in the cold, dry polar air.

Having answered the cold/warm air question, one must now decide how much cut to take. Practice indicates that 30° is about the optimum figure; it will yield a lateral displacement of 0.5 mi from the original track for each mile flown on the interception track and one minute of time will be lost with respect to the flight plan for each seven minutes that the interception heading is held — a 40° diversion will cost nearly twice as much in lost time at a disproportionately small increase in lateral displacement.

How much time to spend in attempting interception? There is, of course, no quick and easy answer to this question; all the factors affecting the particular case must be weighed and a decision made as to the maximum time that it is considered worthwhile to hold the interception heading and if by this time the jet stream has not been intercepted, the attempt should be discontinued and the flight should proceed towards destination.

Now that the interception procedure has been formulated and is ready to be implemented, the intended action must be made known to the appropriate air traffic control center and clearance obtained. Should clearance be unobtainable, nothing further may be done at the present time with regard to jet stream interception.

However, assuming that air traffic control clearance has been obtained and jet stream interception has begun, one must maintain a continuous and careful monitor on the free air temperature as, when intercepting from the cold side, a sharp temperature rise will indicate puncture of the frontal surface and entry into the stream; when intercepting from the warm side, a sharp temperature drop will signal the fact that the aircraft has passed through the stream and on into the cold air on the other side.

The actual rate of change of temperature versus time across the frontal surface is a function of the existing thermal shear at the given flight level and the angle at which the track is converging with the front. A change of 1° in 3 to 5 min is typical. The free air temperature gauge must be monitored carefully in order to locate the thermal break accurately, since it can be missed completely by careless reading, parallax etc.

Altimetry drift must be checked carefully at 15 to 20 min intervals as a double check on the temperature gauge. Altimetry drift refers to the determination of aircraft drift by measuring the slope of the pressure

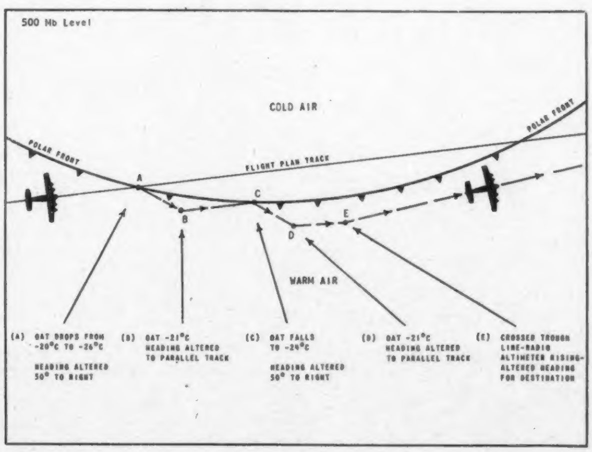


**Figure 8**
**Interception from warm side followed by bracketing of front**

surface along the track with the radio (absolute) and pressure altimeters. A sharp change in drift should more or less coincide with the temperature change at the frontal surface.

The position of the aircraft should also be fixed as frequently as available facilities permit in order that ground speeds and winds may be frequently and accurately determined. The emphasis on accuracy has to do not so much with any requirement for exact knowledge of geographical position as it has to do with wind-finding; the winds determined are the ultimate index of progress with respect to the jet stream and, in order for the winds to be accurate, the fixes upon which they are based must also be accurate.

To restate the point, successful jet stream navigation requires constant careful monitoring of the free air temperature, frequent and careful drift determination and frequent and accurate determination of position.

Figure 8 provides a typical example of navigation tactics in horizontal interception along a jet stream. It will be noted that the temperature gauge is used as the sense element for locating the frontal surface and that the aircraft turns immediately on the temperature drop. This technique is commonly known as bracketing the jet stream.

**JET STREAM EVASION**

In the case of the westbound trans-Atlantic flight, the significance of the jet stream reverses itself. It becomes something to be avoided at all costs, and something to get out of as soon as possible when one unintentionally blunders into it.

The position of the frontal surface at flight levels is of great importance in planning the westbound flight and the least time track very frequently lies well to the north of the frontal area. It is often the case that a large cold-core cyclone dominates the North Atlantic pressure pattern with a jet stream traversing its southern boundary; in such a situation, westbound flights may follow tracks which swing around the top of this cyclone, occasionally crossing the southern portion of Greenland.

In short, jet stream evasion is taken care of in the flight planning phase if sufficient information is available. The use of least time track flight planning as a standard practice tends to keep westbound flights away from the frontal region while great circle flight planning frequently has the opposite effect.

Occasionally, however, a westbound flight which has been dispatched at high level will find itself boring into jet flow. This can be a very serious situation with respect to falling behind flight plan. For example, if one encounters a 150 kt headwind in an area where only a 50 kt headwind is forecast, one will fall behind flight plan at the rate of 30 min for each hour flown (assuming a true airspeed of 250 kts) as long as the situation persists. This is an intolerable condition and evasive action is required.

Descent to a lower altitude where there is, hopefully, less headwind, is instinctive in such a situation; but one also loses true airspeed with descent and, in order to really evade the jet stream, the descent must take the aircraft through the frontal slope, which may be quite low indeed. Descent of only a few thousand feet will rarely do one much good. More often one must go down 10,000 ft or more in order to escape the strong headwinds.

Descent through the frontal slope will ordinarily be the most immediately effective means of evading the influence of an adverse jet stream, but it may not be the

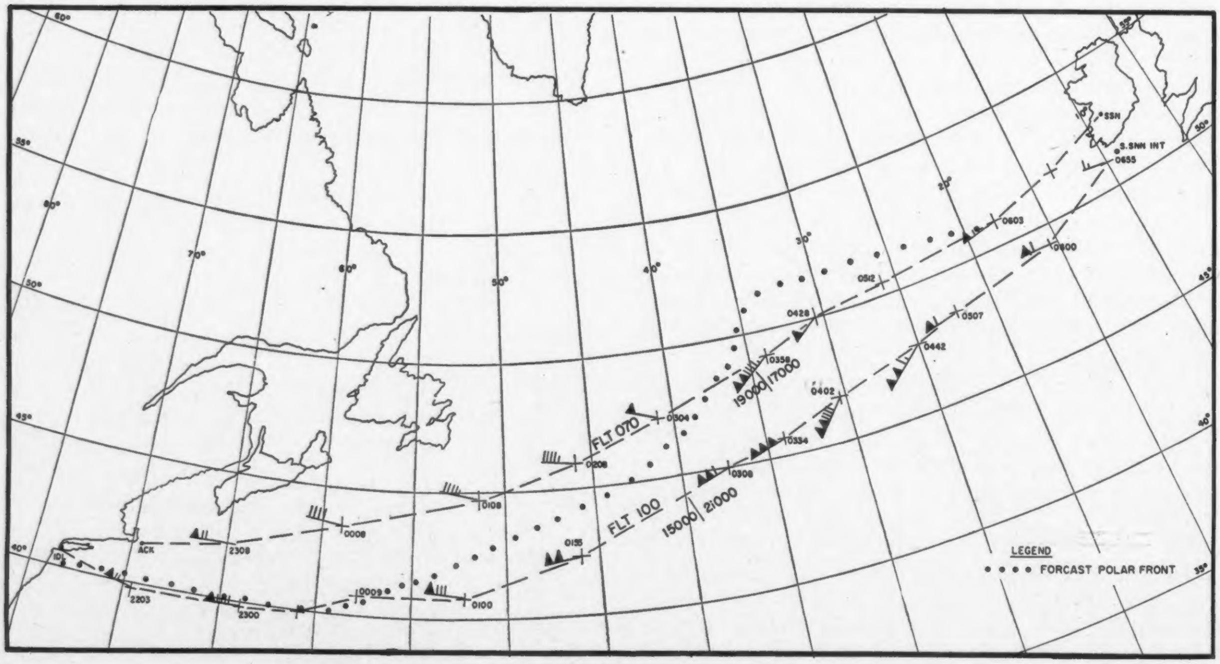


**Figure 9**

best overall solution in a given case as it will incur a marked reduction in true airspeed and perhaps an uncomfortable ride for the passengers in frontal weather etc. and should not be considered the only means of escaping the stream.

It may be possible to make a horizontal deviation to the right, i.e. into the cold air, with its much lighter winds; if such is considered feasible, quite a large course change may be justified as it is essential that the flight get out of the jet stream as soon as possible. The free air temperature gauge will provide the necessary information on frontal penetration, clear air turbulence may confirm it, and it would be advisable to take the flight well into the cold air in order to minimize the headwind and get clear of the clear air turbulence associated with the front.

There are cases on record where a pilot finding himself in an adverse jet stream has actually been able to see the dry, cloudless polar air to his right while he is flying between layers and has therefore diverted visually into the cold air.

It is ordinarily not feasible to attempt to evade a jet stream by means of a lateral deviation deep into the warm air due to the added overall distance involved. Figure 2 provides the reason, the isotachs extending deeply into the warm air south of the core. In the situation where an aircraft finds itself unexpectedly converging with an adverse jet stream from the warm side, descent offers about the only relief unless the stream is known to be quite narrow and a rapid crossing into the cold air may be effected.

To sum up, in order to make use of jet flow when it is favorable or to avoid it when adverse, one need not have only a thorough understanding of frontal structure, but must, above all, be alert for the signals which the jet stream provides and be prepared to take prompt, intelligent action on the basis of these signals.

**COMPARATIVE EXAMPLE**

Figure 9 provides an excellent actual example of the importance of careful track selection in the presence of jet flow. The tracks and winds are the actual tracks flown and winds encountered by two PAA aircraft which departed New York within a few minutes of each other. The factors influencing track selection in this case were as follows. The prognostic chart had been generalized very badly, contour spacing in the cold air being uniform and much tighter than it should have been, which had the effect of displacing the least time track to the north.

Both flights were planned via the same least time track and Clipper 70 flew it as planned. The crew of Clipper 100 took exception to the planned route on the basis of some not too obvious thermal information which indicated that the jet stream passed about a hundred miles south of Nantucket. Their flight plan was thereupon modified to the track shown and was flown accordingly.

The winds reported by the two flights provide striking evidence of wind shear across the front and the critical effect of the front on track selection. Note that Clipper 70 obtained 19,000 ft immediately on initial climb, but that Clipper 100 was held to 15,000 ft out to the fortieth meridian due to traffic at upper levels. Note also that, nevertheless, Clipper 100 experienced 40 to 60 kts more tailwind at the lower altitude. Had Flight 100 been at the same altitude as Flight 70 in the early portion of the flight, its winds would very probably have been another 50 kts higher than they were.


## ANNUAL GENERAL MEETING

**KING EDWARD HOTEL,**

**TORONTO**

**26th and 27th MAY, 1958**

# IMPORTANT FACTORS IN AVIATION SAFETY†

by R. M. Woodham*

*Cornell-Guggenheim Aviation Safety Center*

MANY airlines advertise with slogans to the effect that "your safety is our first consideration". While these slogans are blazoned in all good faith, even a superficial scrutiny of current trends causes many thoughtful people to ponder on their timeliness. In this paper I will attempt to outline a few of the problem areas where more consideration of cause and effect might enhance the safety of flight.

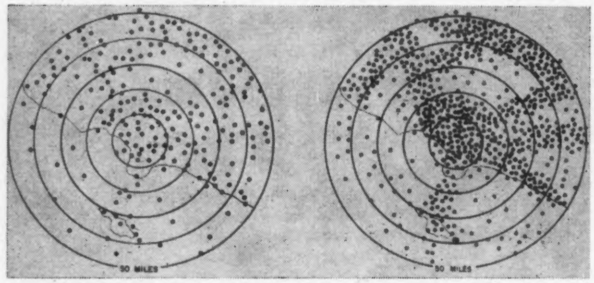


**Figure 1**
**Radar patterns of traffic Los Angeles area 1956 and 1975 (Reference 1)**

## AIR TRAFFIC CONTROL

This knotty problem has been growing rapidly during the last few years, owing partly to the greatly increased amount of airline, business and private flying, and the lack of progress in developing and installing improved electronic and mechanical aids for the controllers. Top-level attention has finally been given to the problem through the studies conducted by the Facilities Planning Group under Mr. Curtis[1], resulting in the report published earlier this year. This document defined the growth pattern of air traffic for the next 20 years, made recommendations for research and development in airways modernization, and proposed organizational patterns to carry on the work more effectively.

An example of the increased traffic in the Los Angeles area is seen in Figure 1 showing simulated radar patterns of traffic at an average busy hour in the Los Angeles area, for 1956 and 1975. Figure 2 shows projected growth of all types of air traffic through 1975.

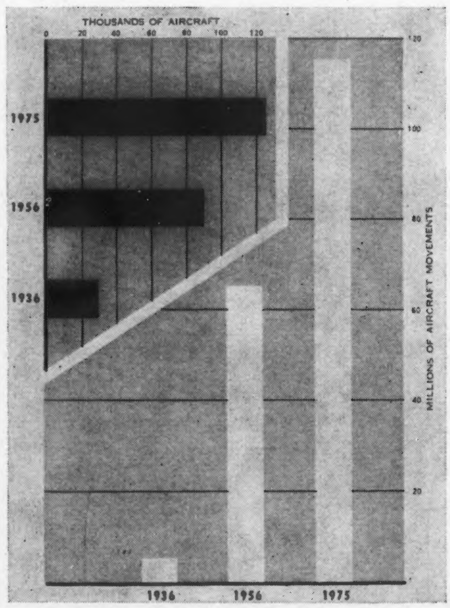


**Figure 2**
**Projected growth through 1975—Number of aircraft and aircraft movements (Reference 1)**

Since this discussion covers more than just air traffic control, we shall not spend more time on the subject than to say there is no magic panacea for this complex situation. Money and concentrated effort must be expended to take positive and rapid strides to achieve a solution before the rising tide of air traffic creates intolerable congestion and delays, not to mention hazards of mid-air collision. We should not wait upon advanced concepts and shiny computers that are under development but make use of adequately developed and reliable equipment to relieve the situation at once.

## MID-AIR COLLISIONS

Although this hazard has been recognized for a long time, little concentrated activity has been apparent until the Grand Canyon disaster in July 1956 shocked the country into taking action. As pointed out above, the rapidly increasing traffic, coupled with higher speeds and more flying in adverse weather, has multiplied the hazards. Even though a system of control in terminal areas and on the airways should reduce the hazard, there

†Paper read at the Joint I.A.S./C.A.I. Meeting in Montreal on the 22nd October, 1957.

*Associate Director.

are still thousands of aircraft flying off-airways and without sufficient radio and navigation equipment to utilize such electronic aids as may be available. The rule of "see and be seen" is rapidly becoming obsolete because of high closing speeds and irreducible physical reaction time. A CAA study of visibility under ideal conditions shows that the average perception occurs at 4 and 5 miles and the maximum possible at a distance of 10 to 14 miles. What this means in the case of jet closure speeds of 1,200 to 1,500 mph can be imagined. Some form of electronic warning device is essential and we are glad to say that efforts in this area are being made. The problem is complex and may require several years for solution.

**HUMAN ENGINEERING**

The importance of human factors in engineering was forced upon the designer with the advent of high performing and complex aircraft. Physical limitations in altitude, acceleration, stress and fatigue are vital in the design of a successful military aircraft, and recognition of these factors in commercial aircraft is also paying dividends. A considerable amount of biological and psychological data is becoming available to the engineer through handbooks, technical reports and specialized courses. A recent survey of aircraft and accessory manufacturers indicates that over 30 companies now support human engineering groups, whereas there were only six such groups as recently as three years ago. The Guggenheim Foundation has established the Harvard-Guggenheim Center for Aviation Health and Safety at the Harvard School of Public Health to provide teaching and research facilities in this inter-disciplinary field.

While we read much of Space Medicine and excursions to high altitudes and high speeds, the problems with which we need to concern ourselves at this time are much simpler. Can we provide the pilot and crew with a good, quiet, ventilated and properly lighted working environment for best efficiency? Can we design the cabin structure for adequate size and number of emergency exits and make them fail-safe? Can we reduce the mechanical complexity of the tower controller's job so that he can efficiently and safely handle a larger number of aircraft in a given time? Can we incorporate elements of instrument flight training into the private flyer's training so as to make him a safer pilot when caught inadvertently in bad weather? All of these involve use of human engineering principles which are known, but have not been adequately considered.

**OCCUPANT PROTECTION**

The designer can improve crash survivability through the incorporation of tested improvements in seats, belts, floors, exits, doors and cabin structure. Figure 3 shows the interior of the cabin of a DC-6 military transport in which practically all the rearward-facing seats tore loose, catapulting their occupants into the front of the cabin. Analyses of several transport crashes show that more than 80% of the survivors were incapacitated through injuries or concussion and had to be assisted from the airplane. Since two out of three accidents occur away from the airport where outside assistance is

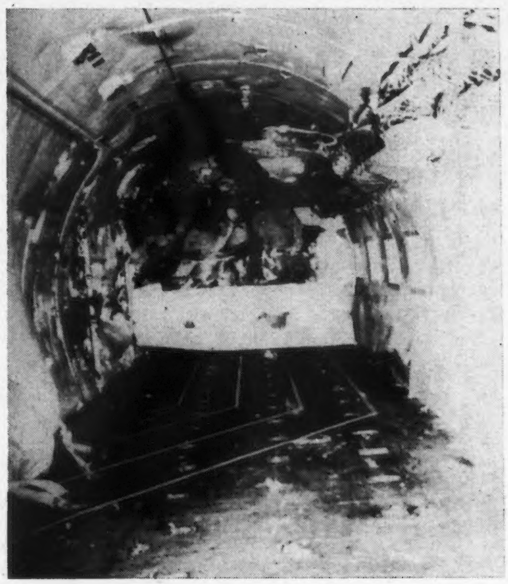

**Figure 3**
**Fort Dix crash—Interior of cabin, DC-6 military transport**

not immediately available, the value of built-in occupant protection is apparent. Incorporation of crash safety features is important in the rapidly growing business airplane fleet, where often more attention is paid to "plush" seats and appointments than to adequate passenger and crew protection.

The operator too can contribute to the safety of flight. For instance, it is known that one manufacturer is building a high wing airplane to carry 40 people with no provision for exits above the water line in the event of ditching. What happens to the submerged passengers in such a case is something to worry the operator. Apart from thoroughly investigating the safety features of his purchases, he can enhance safety in flight by initiating regular and realistic crew training and by installing floatable seat cushions, emergency lights, slide chutes, rescue beacons etc.

Despite the developments over the years to aviation's "golden age", the call for search and rescue still plagues us with an aura of helplessness and hopelessness. This is particularly so when a transport, civil or military, is lost at sea or over uninhabited territory about once a year. There is a crash rescue beacon available for large aircraft and simplified forms of the same device available to small aircraft. This device automatically transmits a coded distress signal for a number of hours which can be picked up by two or more ground stations to provide a "fix" on the downed aircraft.

**CRASH FIRE PROTECTION**

The NACA completed research on reciprocating engined aircraft over 4 years ago and on turbine engined aircraft over a year ago, including development and test of a pressurized water extinguishing system sprayed over the exhaust manifold and into the engine. Although the effectiveness of this system in curtailing catastrophic fires, particularly following minor accidents on forced landings, has been demonstrated, to date no transport

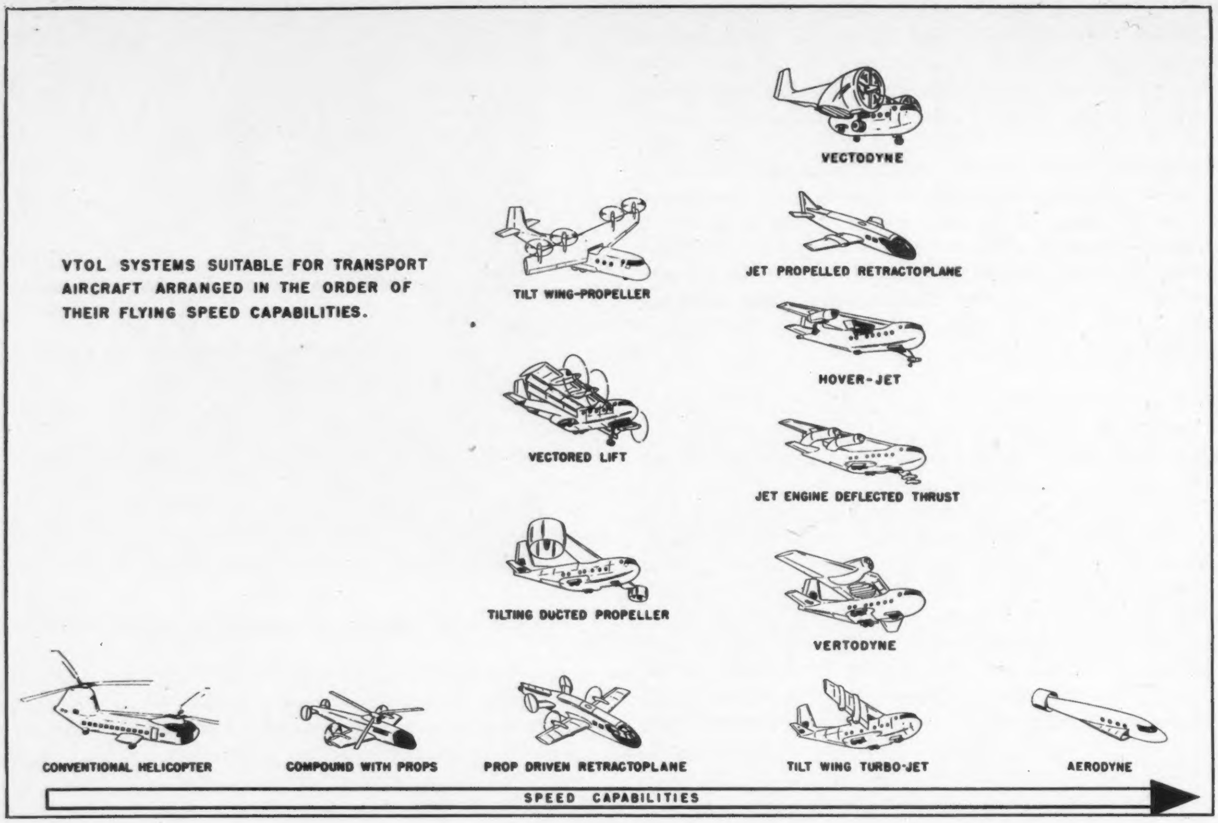


**Figure 4**
**VTOL transport configurations—Vertol report**

has been fitted with such fire protection. Aside from the humanitarian aspect of the problem, the economics of salvaging very expensive equipment after a minor landing accident should indicate the necessity for crash fire protection. We are glad to say that consideration is being given in the jet transports to this type of protection through insistence by some airlines.

I will not go into the merits of gasoline, kerosene, or JP-4 as to relative flammability. There have been a sufficient number of cases on both sides of the Atlantic to show that any fuel, under crash conditions, is highly flammable. Research on crash resistant fabric tanks and fittings is now going on which may provide us with fuel containers that will not rip open and spray fuel around even under severe crash conditions. In the meantime, we ride in transports with fuel carried in the fuselage, wing roots and engine nacelles, areas highly vulnerable to ignition. The fuel weight alone in the 707 is more than the weight of a fully loaded DC-6B transport.

**STEEP GRADIENT AIRCRAFT**

One might think as he looks at the various tilt-wing VTOL or Jet flap STOL configurations in Figure 4, that these have no part in a discussion of aviation safety. Let us therefore say that we are interested in such developments for their potentialities for slow speed controlled landings and take-offs, which permit landings on many more small airports or even unprepared fields. In addition, the STOL aircraft provides greater time for pilot reaction in emergencies and, if a forced landing were inevitable, would reduce the kinetic energy effects which help to make an accident survivable. We are encouraged by the development of such aircraft as the Twin Pioneer and the DHC-4 Caribou, Figure 5, which are designed to operate from very short fields (less than 1000 ft) and yet carry reasonable payloads. The business plane would be an ideal market for a manufacturer who incorporates features of boundary layer control, supercirculation etc, to the present type of small cabin plane, such that it can fly into many small fields adjacent to


**Figure 5**
**DHC-4 Caribou**

mining or ranching operations. However, the safety and controllability features should not be compromised by unreliability of systems, lack of crash and fire protection, or the proper integration of slow flying aircraft into the ATC system.

### PRIVATE FLYING HAZARDS

There are over 65,000 active aircraft in the United States and the success of the business plane is adding thousands more to this number every year. Figure 6, from the Curtis report, shows the expected growth of general aviation, emphasizing business flying. Principal hazards appear to be flight into adverse weather, spiral instability and inadequate training. Because of the limited resources of the manufacturers and operators of these aircraft, long-standing problems have not been solved by research, nor has the small aircraft been able to benefit from the electronic wonders developed for military and airline use.

There have been several studies made indicating that a limited amount of instrument training (possibly as little as 5 hours additional) can give a private pilot the needed technique and confidence to get him safely out of an inadvertent weather emergency. Lightweight single axis autopilots are also being developed to improve the stability of small aircraft, while small size turbine engines promise increased power without weight penalties.

### JET OPERATING PROBLEMS

While military jet operations are over 10 years old, we foresee many problems associated with the introduction of civil jet transports. These are being studied by manufacturers, airlines and government agencies, but their impact on all phases of aviation is so great and the time is so short that we urge concentrated attention

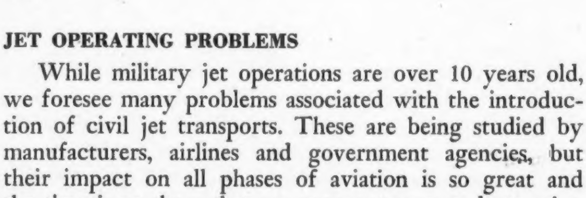


**Figure 6**
**Active general aviation aircraft by primary use (Reference 1)**

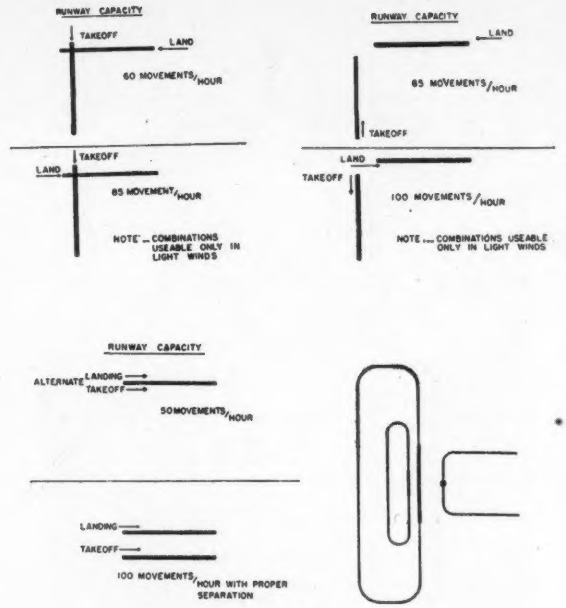


**Figure 7**
**Runway capacity as affected by layout and operations—Warskow**

on the more important of these problems. Present schedules call for 30 jet transports by July 1959 and 215 just one year later. In a paper presented to the Royal Aeronautical Society[2], Mr. Dyment of Trans-Canada listed no less than 46 major problem areas associated with the introduction of jet transports into commercial service. They cover the whole spectrum of training, maintenance, communications, traffic control, meteorology, passenger accommodations and airport design.

Mr. Dyment's excellent paper does not cover such problems as emergency oxygen or rapid decompression on the passenger; accurate weather forecasting both at altitude and on the runway in remote parts of the world where such services are now lacking; maintenance and ground mechanics training on both new airframes and engines, with tolerances that are in general much less than for piston type aircraft; or the matter of senior pilot selection for the new planes versus the loss in visual acuity and reaction time among older persons.

### AIRPORT MODERNIZATION

The current congestion at terminals indicates that we are far from ready for larger aircraft with double the passenger load of present transports. From a safety standpoint, there are many things that can be done at relatively modest cost to give the present airports a higher capacity. Figure 7, from a paper by Mr. Warskow of the New York Port Authority, shows several operational steps that can be put into practice to increase runway capacity almost 50%. It is also possible to use improved methods of marking and lighting runways and taxiways to expedite movement of aircraft on the ground. High speed turnoffs are already being built. A study of gate positions or busses to relieve congestion at loading gates may improve airport capacity. Terminal air traffic

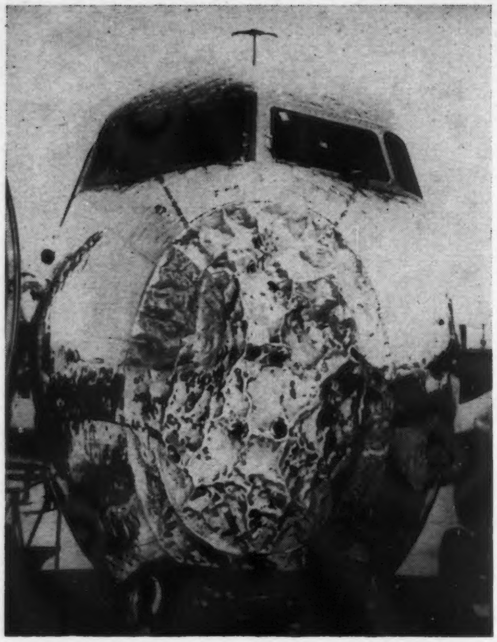

**Figure 8**
**DC-6 nose after hailstorm**

control can also be expedited by utilizing some of the new communication techniques being developed, and installation of a low cost GCA, such as Quadradar for small airports, would expand IFR operations. A shorter runway parallel to the main runway can often be laid out within the limits of a present-day airport and would relieve the main runway of all itinerant and feeder line traffic. Because of the terrific cost of runways and airports today, all possibilities for obtaining maximum use of existing facilities should be required before embarking on a new airport program.

**WEATHER FORECASTING & COMMUNICATIONS**

Weather is still the bottleneck to achieving regularity of operation for all types of aircraft. Figure 8 shows the damage done to a DC-6 by flying 60 seconds through a hailstorm. In particular, high altitude jet operations require certain knowledge of ground conditions at destination and information on upper air conditions which are now only partially available. It is also necessary to have more accurate ceiling, horizontal visibility and runway visual range at the airport in order that jets can descend and make successful landings, without the hazard of "wave-offs". For private and business flying, there are many "blind" areas between weather stations, which are gradually being covered by long-range radar and automatic weather reporting stations. Research on upper air mass flow and a more complete network of weather stations are under way. Turbulence and icing conditions in flight are being avoided through use of airborne radar. Short-range forecasting, high intensity approach lights, and experiments in clearing fog via cloud-seeding techniques promise aid in the approach and landing problems. Greater coordination of weather information to provide accurate and frequent local and long-range forecasts is a vital necessity.

**CONCLUSION**

We do not intend to be pessimistic about the status of safety in present or future operations. The excellent record of the airlines in the last few years indicates that safety has been given major consideration. But we do want to emphasize that constant attention and even foresight are necessary to maintain this record while carrying more passengers at higher speeds to more places than ever before.

REFERENCES


(1) *Aviation Facilities Planning*, FINAL REPORT BY THE PRESIDENT'S SPECIAL ASSISTANT, MAY 1957 (familiarly known as the Curtis Report).

(2) Dyment, J. T.—*The Problems of Jet Transport Operation*, JR. R.AE.S., PP 594-608, SEPTEMBER 1957.

# GAS TURBINE COMBUSTION SYSTEM DESIGN†

**by F. D. M. Williams***

***Orenda Engines Limited***

## INTRODUCTION

It is the intention to discuss in this paper the design rules and simple analytical approach employed in the process of evolving and evaluating a combustion system design for a specific project, such as an advanced type of jet engine. The general application of the science of combustion to aero gas turbines has been amply covered by recent papers, such as that given before the Royal Aeronautical Society by Dr. J. S. Clarke on November 10, 1955[1].

Reference to the problem of designing a combustion system for an aircraft of high supersonic speeds above Mach 2.0 is made later in the paper, where a brief coverage of one approach helps to illustrate future trends and their attendant problems.

## THE DESIGN PROGRESS

As a general rule, the project designer will specify boundaries within which the combustion system must fit. These are defined by the projected engine size and weight, which are held to an absolute minimum, and may be categorized as follows:

(1) compressor delivery annulus dimensions,
(2) turbine annulus dimensions,
(3) turbine inlet temperature distribution,
(4) combustion casing inside and outside diameters, and
(5) overall length.

These boundaries are, of course, established after consultation with the combustion engineers, and more particularly the aerodynamicists, who define engine air mass flow, compressor delivery temperatures and pressures, permissible combustion pressure loss and turbine inlet maximum temperature.

Items (1) and (2) are, of course, defined by the aerodynamics of the compressor and turbine and item (3) by turbine blade stresses in terms of the maximum operating inlet temperature. Items (4) and (5), however, are a compromise in terms of:

(a) shaft diameter (this is a function of its unsupported length) which defines the inner casing diameter,
(b) engine frontal area which defines the outside diameter of the combustor, and

(1) PRESSURE LOSS FACTOR $(P.L.F.) = \dfrac{\Delta P}{\frac{\rho_3 v^2}{2g}} = \dfrac{\Delta P}{\frac{Wa^2}{2g \rho_3 A^2_{(MAX)}}} = 18$ to 20

INLET VELOCITY $= \dfrac{Wa}{\rho_3 A_{(MAX)}} = 120$ FT/SEC WHERE $\rho_3 = \dfrac{P_{3t}}{RT_{3t}}$

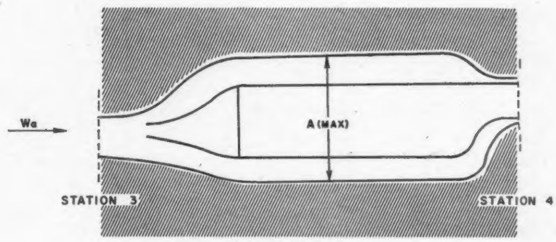


**Figure 1**

(c) length required for the diffusion of the inlet air, and flame tube volume which is determined by acceptable levels of combustion intensity defining the overall length of the combustor.

Having defined the combustor maximum cross-sectional area by engine frontal area and inner casing diameter, we can examine the effect of engine compression ratio on the combustor inlet velocity (Figure 1). The inlet velocity is generally expressed in terms of the air casing maximum cross sectional area and inlet density based on compressor delivery total head temperature and pressure. An explanation for the selected value for the velocity of 120 ft/sec follows from Figure 2[2], in which we see that the optimum compression ratio for maximum aircraft range is of the order of 7, which corresponds to combustion inlet velocities approaching values of 120 to 140 ft/sec. Referring to the non-dimensional pressure loss factor, as defined by Eq. (1), Figure 1

$$PLF = \frac{\Delta P}{\frac{\rho_3 v^2}{2g}} = \frac{\Delta P}{Wa^2\, 2g\, \rho_3\, A^2_{(max)}} = 18 \textit{ to } 20$$

The PLF is defined as the pressure drop divided by the inlet dynamic head from the compressor, once again written in terms of the inlet density $\rho_3$. The pressure

†Paper read at the Joint I.A.S./C.A.I. Meeting in Montreal on the 21st October, 1957.
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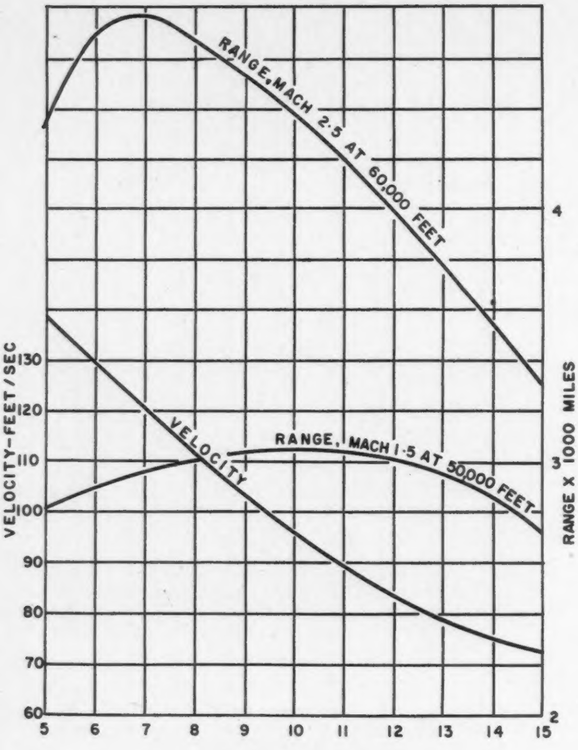



**Figure 2**
**Component design parameters**
**Flight Mach No. 1.5, Altitude 50,000 ft**

loss factor is thus the number of inlet dynamic heads lost in the combustor.

In terms of the present state of the art, pressure loss factors of the order of 18 to 20 are necessary and by limiting the maximum velocity to 120 ft/sec, the loss in compressor total pressure will not exceed 7½% for an 8/1 compression ratio engine (as shown in Figure 3). It may be noted that an increase in inlet velocity from 120 ft/sec to 180 ft/sec would provide an increase in pressure loss from 7% to 17% and this results in a substantial loss of engine thrust potential.

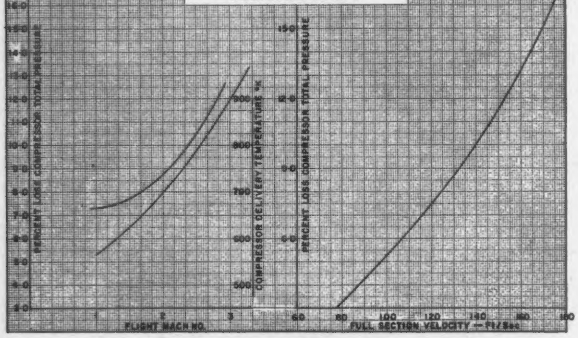



**Figure 3**

| COMBUSTION INTENSITIES | | PERFORMANCE CRITERION | STANDARD |
|---|---|---|---|
| 1. PRIMARY ZONE VOLUME | $10 \times 10^6 \frac{CHU}{HR.ATM.FT^3}$ | COMBUSTION EFFICIENCY | 96 TO 99% |
| 2. FLAME TUBE AREA | $5.0 \times 10^6 \frac{CHU}{HR.ATM.FT^2}$ | STABILITY RANGE | 25/1 TO 400/1 |
| 3. FLAME TUBE VOLUME (OVERALL) | $2.0 \times 10^6 \frac{CHU}{HR.ATM.FT^3}$ | TEMPERATURE DISTRIBUTION | $10\% \frac{\Delta T}{T\ MEAN\ °K}$ |

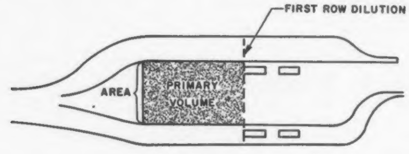



**Figure 4**

The overall length is, as stated earlier, established by combustion intensities. Combustion intensity is defined here as the heat release in centigrade heat units per hour per cubic foot of space per atmosphere of pressure under which the combustion reaction takes place. For a conventional oil fired boiler, this could be defined simply as the pounds of fuel consumed per hour divided by the volume of the reaction chamber and would amount to 2.5 lb/hr ft$^3$ per atmosphere. On this basis it would be compared with a value of 200 for the aero gas turbine. There are three combustion intensity factors which, in the opinion of the author, are of importance. These are set out in Figure 4, together with what might be considered upper limits by present day standards.

These three combustion intensity factors, broadly speaking, govern respectively the combustion efficiency, combustion stability range for a given pressure loss and outlet temperature distribution.

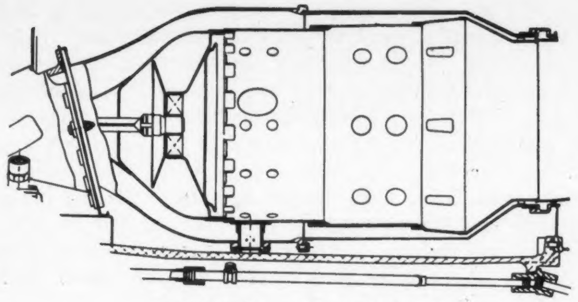
It is possible to compromise on area intensity if pressure loss is not important, or on overall intensity if the temperature distribution is not critical in terms of blade stresses. There will always be a tendency in new engines to work to optimum turbine blade stresses in terms of engine weight and this will limit the extent to which overall intensities increase for a given combustion system. There is little doubt, however, that overall combustion intensity values will reach $3.5 \times 10^6$ CHU/hr atm ft$^3$ in the near future.

Earlier practice has been to base the design on sea level static conditions. More recently, however, it has been necessary to examine the conditions over the entire operating range of the airframe for which the engine is intended.

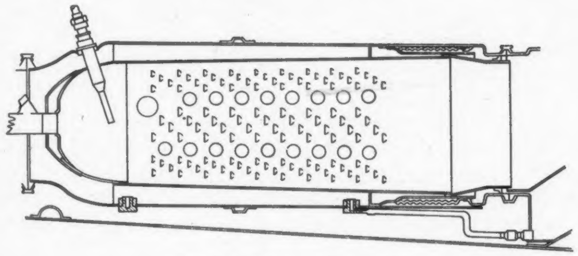
At this stage we must assume that the designer has some development experience and detailed knowledge of some well-proven type of combustion system which he has selected as being best suited for the particular application. Some examples of combustion system types are shown in Figure 5 and are as follows:

(1) Axial swirler type. Can or annular.
(2) Simple baffle type. Can or annular.
(3) Vapourizing type. Annular.

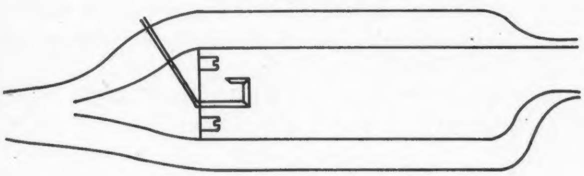
The design example presented in this paper is for the third type listed, that is an annular vapourizing combustion system where we have set out the design targets as shown at the top of Figure 6.



(1) **Axial swirler type**



(2) **Simple baffle type**



(3) **Vapourizing type**

**Figure 5**

At this stage the turbine annulus is divided into inner and outer portions in an approximate ratio of the inner and outer flame tube surface areas and the flow split for the inner and outer annuli is chosen so as to provide a mean outlet temperature for these portions to approximate the desired profile.

Approximately 20% of the inlet air completes the combustion reaction in the primary zone and we can, therefore, calculate the gas temperature from the primary zone. Knowing compressor delivery air temperature, we can arrive at the necessary flow split to obtain the desired average temperatures. In this particular case, the flow split was determined as shown in Figure 6. The annulus areas are then selected to provide velocities not exceeding 300 ft/sec so as to avoid excessive pressure losses in these flow passages, keeping in mind that the flame tube cross-sectional area must be as large as possible to keep the area intensity within limits. When annulus velocities are too high, it is difficult to appreciably influence the air flow split between the primary zone and mixing region by changes in mixing holes etc. Changes are invariably necessary in the course of rig development to improve operating characteristics, such as combustion efficiency and temperature distribution. In the particular design described here, we were able to approximate the desired profile to within 20°C, as measured on the test rig.

The flame tube area intensity and overall volume

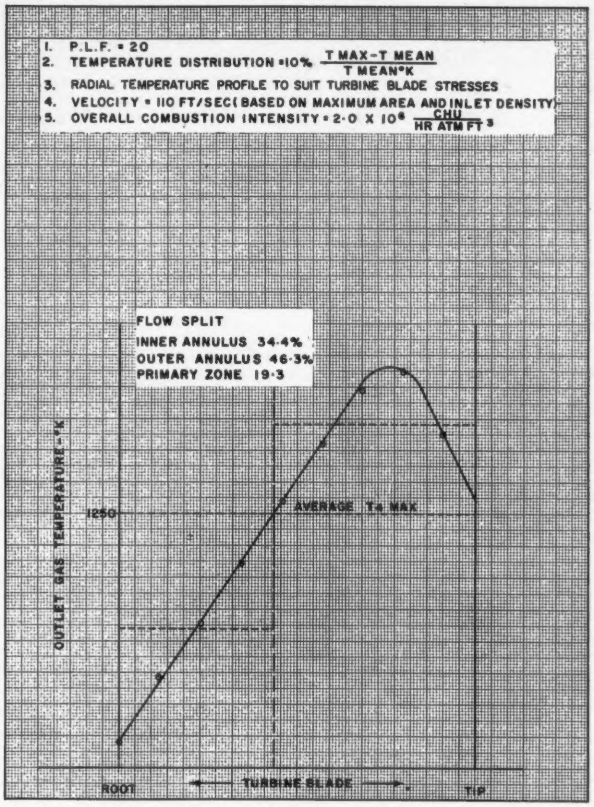



**Figure 6**

intensity are calculated and were determined for this design as follows:

Primary zone
volume intensity $= 9.78 \times 10^6$ CHU/hr atm ft$^3$
Flame tube
area intensity $= 4.70 \times 10^6$ CHU/hr atm ft$^2$
Overall intensity $= 2.0 \times 10^6$ CHU/hr atm ft$^3$

These values are all within the limits of acceptability stated in Figure 4 and the detailing of the flame tube geometry is next carried out. These results are shown in Figure 7.

In large engines the diffuser generally employs a geometric divergence of 12° to 15° up to the plane of the flow split in an endeavour to compromise between minimum length and maximum diffuser efficiency. Flow separation must be avoided at all costs or the combustor performance will suffer not only from a

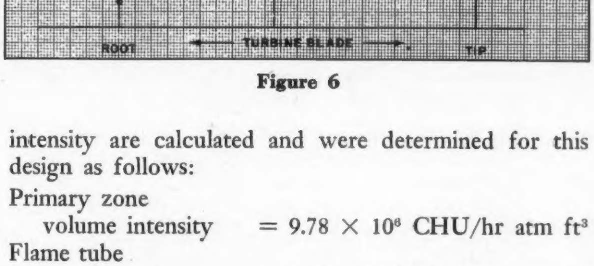



**Figure 7**

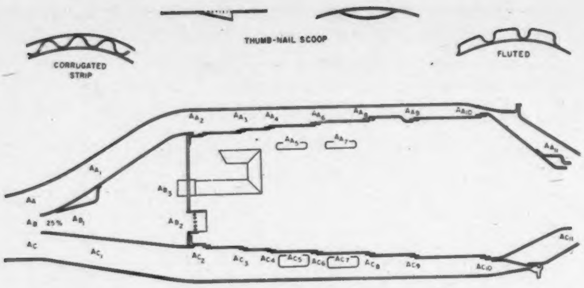



**Figure 8**

standpoint of pressure loss, but also from the standpoint of efficiency and consistency of outlet temperature distribution.

The snout intake is sized for approximately 25% of the air mass flow, which is 5% in excess of the actual flow, helping to improve flow conditions in this plane by initiating streamline divergence prior to the flow split.

The baseplate or stabilizing mechanism is either scaled from an early proven design or based on other development experience, but in any event must be calculated to supply most of the primary air for the combustion process, the chemically correct mixture being approximately 14.6/1 for standard jet fuels.

The flame tube walls generally employ some method of skin cooling, such as annular gaps spaced by corrugated strips, fluting of one or other of the adjoining sections or by louvres, which are sometimes called 'thumbnail' scoops, as shown in Figure 8.

Assuming that the materials used are Nimonic 75, Inconel X or type 310 stainless steel, sufficient cooling should be provided to maintain wall temperatures below 700°C. Thermal paints are generally used to determine these temperatures during rig and engine testing.

The upstream edge of the first dilution ports has already been determined by the selected primary zone volume intensity. The spacing of the holes is optimized on rig test when temperature distribution trimming is undertaken, but, in general, circumferential spacing is adjusted to ensure correct penetration of the annulus air, the rows being placed in axial alignment to assist penetration. The area of these holes is determined from the flow analysis outlined later in this paper.

Finally, a seal with positively controlled leakage is included at the downstream end to avoid very low temperatures at the root and tip of the turbine blades.

This design feature is very important as it avoids costly engine development work at or near the production stage, when inconsistences from engine to engine are likely to show up due to lack of control of air flow at this point.

**FLOW ANALYSIS**

In conjunction with the foregoing, a flow analysis is carried out which assures the combustion engineer that he will be operating within the specified limits of pressure drop or pressure loss factor.

(1) Referring to Figure 8, $A_{A_2}$ to $A_{A_{11}}$ (effective areas) are in parallel and, analogous to electric conductances, can be added arithmetically.

(2) $A_{A_1}$ is the effective area of the diffusing and turning passage and must be calculated from Eq. (3) of Figure 9, once we have arrived at the pressure drop which can be determined by reference to literature on diffusers.

(3) Substituting $A_{A_1}$ into Eq. (1a), which is analogous to addition of electrical conductances in series, we arrive at $A_A$. The snout and inner annulus circuits are similarly treated to give $A_B$ and $A_C$ – which add arithmetically to give the effective area of the complete flame tube (Eq. (2)).

(4) It should be noted that discharge coefficients need to be known for the various holes, slots, cooling gaps and baseplate elements.

(5) Calculate pressure drop and PLF from Eqs. (3) and (4).

The usual procedure is to select the size of holes, slots, cooling gaps etc., and proceed with the calculations on a trial and error basis to arrive at the desired PLF.

$$\Delta P = \frac{Wa^2}{2g\rho_3 A^2_{\text{(effective)}}}$$

yields the value for the pressure drop which, when divided by the inlet dynamic head, gives the pressure loss factor.

(6) A calculation of the transit time is made in accordance with Eq. (5).

$$T = \frac{\text{Flame Tube Vol}}{A_{\max}} \frac{T_3}{T_4 \text{ F.S.V.}}$$

The transit time is the average taken for an element of air to pass through the combustion chamber and is, to a great extent, a measure of the combined combustion intensities.

$$A_A = \frac{1}{\sqrt{\frac{1}{A_{A1}^2} + \frac{1}{\Sigma(A_{A2 \text{ to } 11})^2}}} \qquad \text{-1a}$$

$$A_B = \frac{1}{\sqrt{\frac{1}{A_{B1}^2} + \frac{1}{\Sigma(A_{B2 \text{ to } 3})^2}}} \qquad \text{-1b}$$

$$A_C = \frac{1}{\sqrt{\frac{1}{A_{C1}^2} + \frac{1}{\Sigma(A_{C2 \text{ to } 11})^2}}} \qquad \text{-1c}$$

$$A_{\text{(effective)}} = A_A + A_B + A_C \qquad \text{-2}$$

$$\Delta P = \frac{W a^2}{2g\,\rho_3\, A^2_{\text{(effective)}}} \qquad \text{-3}$$

$$\text{P.L.F.} = \frac{\Delta P}{2g\,\rho_3\, A^2_{\text{Max}}} \qquad \text{-4}$$

$$\text{Transit Time} = \frac{\text{Flame Tube Vol.}}{A_{\text{Max.}}} \frac{T_3}{T_4 \text{ F.S.V.}} \qquad \text{-5}$$

__Discharge Coefficients__

| | |
|---|---|
| Cooling Air Gaps | 0.96 |
| Dilution Ports | Function of annulus velocity and pressure drop across flame tube wall usually 0.50 to 0.55 |
| Primary Pipes | 0.56 |
| Secondary Pipe Slots | 0.62 |
| Secondary Pipe Holes | 0.88 |

**Figure 9**

Values of 6 milliseconds are quite acceptable and should avoid mixing problems and low combustion efficiencies.

Whereas the flow analysis may seem to be very approximate, the table below indicates that these calculations can be quite accurate enough for engineering purposes.

| | Calculated PLF | Measured PLF |
|---|---|---|
| Chamber A (Can type with Axial Swirler) | 32.4 | 30.3 |
| Chamber B (Can type with Axial Swirler) | 36.3 | 33.4 |
| Chamber C (Annular Vapourizing Type) | 18.0 | 18.1 |
| Chamber D (Annular Vapourizing Type) | 14.8 | 18.0 |
| Chamber E (Annular Vapourizing Type) | 19.3 | 18.5 |
| Chamber F (Annular Type) | 10.9 | 6.6 |

In addition to predicting the pressure loss of the combustor, the flow analysis can be expanded to indicate the fuel air ratios obtaining throughout the combustion process. This is illustrated in Figure 7 in a somewhat arbitrary way in which the air fuel ratios are quoted assuming that all the air is completely mixed once it enters the flame tube. This information, when compared with the analysis of proven combustors, is a very useful guide in the rig development which must follow.

A brief examination of Figure 7 would suggest that the primary zone is too rich and carbon deposition might become a problem at high inlet pressures. The weak limit blow out air fuel ratio should be well above 400/1, which is the normal limit to be expected for this type of chamber. Both of these facts were borne out in early tests when heavier deposits than are normally considered satisfactory were observed on engine test and the weak limit was measured on the rig at approximately 550/1 at one atmosphere inlet pressure.

Subsequent to the completion of the geometric design a rig test unit is manufactured and tested, probably six months in advance of the first engine test. This gives the combustion engineer sufficient time to optimize the combustor performance in terms of his original targets.

It is imperative that the combustion system does not compromise development during the initial proving stages of the basic engine. To achieve a competitive engine thrust weight ratio, engine designs cannot always be compromised, as in the past, to make combustion systems removable without an engine strip. For this reason a combustion system should operate satisfactorily for at least 25 to 50 hrs from the outset. Obtaining this measure of initial reliability has become progressively less difficult through the years and the point has now been reached where these targets are readily met. However, the pressing need for saving both space and weight and for operating at much higher altitudes brings along a host of new problems. It is becoming increasingly apparent that more time will have to be devoted to combustion system development during the early stages of engine development, so that the degree of reliability currently being experienced will also be shared by future designs. This, of course, is dependent upon the amount of financial support given to the combustion engineers in advance of engine requirements.

Rig development is extensively used in developing a proper ignition system configuration for the combustor if an air exhauster is available which will enable tests to be conducted at chamber pressures of 3 to 4 psia.

The problem of high altitude ignition arises from the reduced number of collisions of the reactants, fuel and oxygen, at low pressures and temperatures. Ignition has been assisted to a very large degree in the last decade by the introduction of condenser discharge systems in which the stored energy is as high as 12 joules. Ignition has thus been made possible up to altitudes approaching 50,000 ft where compressor outlet pressures are in the order of 2 psia. The inlet air velocity for altitude relights at subsonic speeds is generally of the order of 60% of the design inlet velocity (70 ft/sec is representative).

Supersonic applications tend to accentuate these ignition problems as relight limits must be extended beyond 65,000 ft and inlet velocities are of the order of 120% of the design value (of the order of 130 ft/sec).

Recent acceptance of the idea of using oxygen injection to assist ignition has enabled substantial improvements to be made, to an extent where relight should be possible to the operational ceiling of the aircraft at supersonic flight speeds. Oxygen systems may appear either in the form of a flame with a total energy of approximately 7,500 joules from a premixed fuel and oxygen injector or by judicious introduction of oxygen in the vicinity of a well-developed conventional plug arrangement. The advantage of the latter system is that failure of the oxygen system does not render relight impossible as it would be with the premixed injector. Light-up can thus generally be effected at some lower altitude, in the region of 30,000 to 35,000 ft, without oxygen.

Specific demands of the aircraft system in respect of engine idling has resulted in increased idling speeds at high altitude. The normal practice of relighting the combustor with full idle fuel flow may have to be discontinued to avoid rich extinction following light-up. Here the liquid fuel present rapidly vapourizes on light-up, resulting in an over-rich mixture in the primary zone. This was experienced on the Orenda a few years ago where altitude idling requirements were less difficult to cope with than present supersonic engine applications.

Following rig development work in the combustor to achieve the performance targets, the mechanical reliability aspects of the system must be established during the engine development running. Changes introduced during this stage must be completed and rechecked with regard to their effect on performance.

An interesting problem arose on the Orenda at the time the Series 11 was put into service. A minor reduction of primary zone air was made to cure a serious mechanical limitation on the flare of the earlier combustion chambers. With this later series of engine, smoke was observed to be more prevalent under certain atmospheric conditions (which apparently bore no relation to atmospheric humidity, ambient temperature or general visibility, cloudiness etc). Rig testing, employing a photocell to detect exhaust smoke, showed the

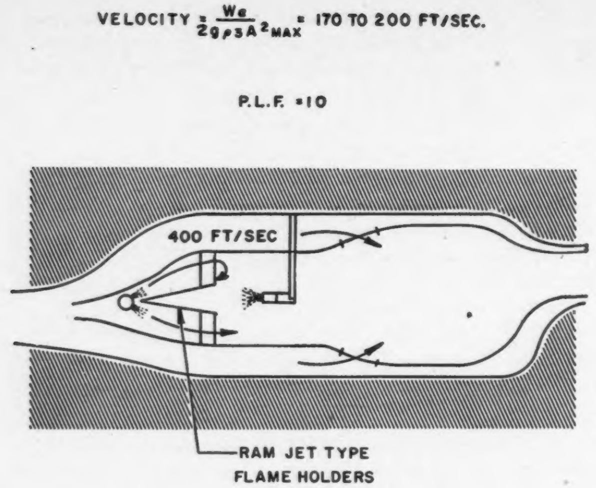



**Figure 10**

new design to produce approximately four times as much exhaust carbon.

Restoring the primary air by the introduction of another row of small holes in the flare corrected the difficulty on the test rig, but subsequent flight testing at high altitude produced flame-outs on rapid deceleration due to the leaner mixture in the primary zone. This condition was not apparent on the test rig during weak limit stability tests, although a slight deterioration was suspected.

### FUTURE DESIGNS

Prior to concluding, the author wishes to present a brief glimpse of future requirements and design trends.

Referring to Figure 3, the inlet velocity to the combustor of any engine remains substantially constant up to flight speeds of Mach 1.5. Above this speed the inlet velocity shows a marked tendency to increase and, in fact, reaches a value of 160% of that at sea level static at a Mach number of 2.5. As mentioned earlier, the pressure loss is now quite significant in terms of overall engine performance and, hence, pressure loss factors must be reduced to the order of 10. It may also be noted that the compressor delivery air temperature is substantially increased. With a fixed turbine inlet temperature, the combustor temperature rise is thus reduced at higher Mach number flight conditions.

An examination of available information immediately suggests applying the technique employed in ram jet combustion systems, where velocities of 200 to 400 ft/sec are quite common. One trend will be toward a system such as that shown in Figure 10.

Primary zones will offer much less obstruction to the air flow, stabilization will be done in the wake of gutter type bluff bodies and a more discrete type of piloting will be used with main fuel being injected upstream of the stabilizer to take advantage of the heat addition to the fuel when it is premixed with compressor delivery air.

Annulus velocities will be increased to a point where little pressure loss will be available for mixing, the dilution air being directed into the flame tube without restriction at the mixing ports.

The combustion engineer's challenge will be one of meeting performance requirements over much wider ranges of inlet velocity and temperature.

High combustion efficiency and satisfactory outlet temperature distribution may be readily achieved at the high Mach number where heat release is considerably lower; however, it will still be necessary to operate at sea level static inlet conditions with high heat release and lower inlet temperatures with comparable levels of performance. There will be no change in the requirement for a wide stable range of operation in terms of air fuel ratio to cater for engine transient conditions.

As has been shown, compressor delivery temperatures at high Mach numbers will exceed 800°K making wall cooling a very real problem in which a great deal of skin cooling may be needed. This will tend to introduce a flame chilling problem at sea level static conditions when lower inlet temperatures are encountered, resulting in losses in combustion efficiency and reduction in stability range. Control of the combustion process is thus made much more difficult and this is accompanied by the mechanical reliability problem mentioned.

In conclusion, it should be pointed out that a discussion of materials and material properties used in present-day combustion systems has been purposely omitted, as this has been adequately covered in recently published literature.

The endeavour has been rather to document present-day performance levels, design criteria and a design method which has been used successfully in scaling combustion systems to several particular applications differing quite widely in stringency of requirements.

**ACKNOWLEDGMENTS**

The author's thanks are due to Orenda Engines Limited for permission to publish this paper, as well as to his colleagues at Orenda for their work in connection with the presentation.

## REFERENCES

(1) Clarke, J. S. — *A Review of Some Combustion Problems Associated with the Aero Gas Turbine*, Journal of the R.Ae.S., April 1956.

(2) Keast, F. H. — *Choice of Design for an Advanced Turbojet*, Can. Aero. Journal, Vol. 2, p 322, November 1956.

# TECHNICAL FORUM

## Foreign Objects in Aircraft, Engines and Airborne Equipment

WITH regard to the Foreign Object Damage Symposium held recently in Ottawa, I consider the report in the C.A.I. Journal was very effective and contained a good amount of useful information which should help to improve the situation. We recognize this as a very serious operational problem with jets and there have been many meetings, papers and reports prepared on the subject. A short search into recent literature should turn up quite a bit of information.

Two excellent reports which I have already referred to Mr. J. L. Orr are "Aircraft Gas Turbine Engine Foreign Object Damage Protection" prepared by the Oklahoma City Air Materiel Area, Tinker Air Force Base, Oklahoma. This report contains a large number of items for various operating people to review and check off to improve the foreign object damage situation. There is an article in the Naval Aviation Safety Center's magazine "Approach" for December 1957 entitled "Foreign Object Damage – Are We to Live with it?" There is also a recent NACA Technical Note on this subject.

If a committee is set up by the CAI or AITA, I would suggest that at least one member (probably a military member) attend some of the USAF Directorate of Flight Safety Research meetings on this subject. If he is a military member, there will be no security clearance required for attendance.

We appreciate your reference to Flight Safety Foundation's Design Notes in the article. We have been endeavoring to develop a Design Safety Check List or a Design Safety Manual which we feel would be more valuable than detailed specifications in promoting safety in design and operation. We have been unable to find the time to develop either of the above projects. It is suggested that it might be handled as a thesis or engineering project by one of the aeronautical engineering schools and we would be happy to supply background information.

Your reference to field service representatives acting as advisers to the designers is the basis for design safety engineering groups in this country. In almost every case one or more of the group is a former representative, usually military, and this has worked out quite satisfactorily.

We agree that the engine and equipment designer should not be penalized for lack of cleanliness on the runway or taxiways. However, this situation does exist and will probably continue to do so. It behooves engine and propeller designers in particular to review their installed layouts and make them less sensitive to damage from foreign objects. On the other hand, there are many things that can be done in operating aircraft to improve this situation. These are contained in several of the current reports. Some of these items are as simple as taxiing at reduced throttle, never using wide open throttle in front of another aircraft, taking off with sufficient interval to permit dust and dirt to settle again, and wetting down or stabilizing dusty areas adjacent to the runways.

We trust the above may be of some interest in this general problem and if further action is taken on the subject, we should be pleased to learn about it.

Cornell-Guggenheim
Aviation Safety Center

R. M. WOODHAM

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# C.A.I. LOG

## SECRETARY'S LETTER

### MID-SEASON MEETING

We shall have to go to press with this letter before the Mid-season Meeting has taken place and so I cannot comment on it now. However the preparations for the meeting have occupied a good deal of our time recently and provided one of the reasons for my touring our western Branches at the end of January.

### WINNIPEG

On the 28th January, on the outward journey, I visited Winnipeg and attended a Branch meeting that evening. Although I had been to Winnipeg three times before (including the Mid-season Meeting last year) I had never been lucky enough to time any previous visit to coincide with a formal meeting of the Branch. Mr. A. D. Wood of the N.A.E. spoke on this occasion; but I will leave it to the Branch Secretary to report on the meeting itself.

While I was there I had an opportunity for a chat with the Branch Chairman, Professor C. M. Hovey, about C.A.I. affairs and then, just before the meeting, Mr. Wood and I had dinner with some of the Branch Officers.

It was a great plesaure to meet many old friends and to make several new ones among our members. I am beginning to know Winnipeg quite well.

### VANCOUVER

The next morning Mr. Wood and I, in separate aeroplanes but by similarly eventful journeys, made our ways to Vancouver; there was fog on the prairies, cloud over the mountains and plenty of rain on the coast; but we got there. By this process of following the route of a much sought-after speaker, I again succeeded in visiting a Branch on a day when a meeting was to be held. Vancouver Branch meetings are always pleasant affairs.

I stayed in Vancouver over the following day; in the morning I surveyed the site of the Mid-season Meeting and discussed the arrangements for it with Mr. H. H. Ollis, the Branch Chairman; and in the afternoon, I had a session with the Specialist Services Committee. We reviewed the work that this Committee has been doing and some of its recommendations which are now ready for submission to the Council. I should like to talk about them now, but that would be premature.

In passing, I think that I am right in saying that this has been the first year that any administrative committees of the Institute have been located at Branches other than Ottawa, Toronto and Montreal. We have the Specialist Services Committee in Vancouver and the 50th Anniversary Committee, on the other side of the continent, in Halifax-Dartmouth. It is a plan to be commended; for these Branches, less frequently in contact with the central organization, often see things from other viewpoints and can contribute some refreshingly new thinking to old problems. I thoroughly enjoyed my talks in Vancouver.

### CALGARY

On Friday, the 31st January, I left Vancouver and headed for Edmonton, spending the middle part of the day in Calgary. The small group of members in Calgary has been growing slowly towards Branch stature, with some quickening of the pace during recent weeks, and I wanted to talk to their Interim Secretary, Mr. J. D. Zmurchyk, about these developments.

Mr. A. R. G. Leckie, Head of the Department of Aeronautical Engineering at the Provincial Institute of Technology and Art, met me at the airport and I had lunch with him and Mr. Zmurchyk at the Institute. After lunch I had an opportunity to say a few words to the Aeronautical students, some of whom are already members of the C.A.I.

The prospects for the establishment of a Calgary Branch are now fairly promising. In the past, the difficulty has been to extend the influence of the C.A.I. outside the four walls of the Provincial Institute, but this deadlock seems to have been broken and a much wider interest in the formation of a C.A.I. Branch is beginning to emerge.

**EDMONTON**

And so on from Calgary to Edmonton, just in time to attend another Branch meeting. This time the speaker was Dr. E. P. Cockshutt of the N.R.C. (Why do I have to travel so far across the continent to hear all this talent from my home Branch?) Mr. Pitfield, General Manager of Northwest Industries Limited, honoured us with his presence; it was a great pleasure to have him with us. It was a good meeting. There was plenty of discussion, which went on for some time in little groups, after the adjournment; in fact, when Mr. J. W. Bristow, the Branch Chairman, and I retired to a quiet corner, we had some difficulty in getting off Dr. Cockshutt's subject and onto Branch affairs.

Having attended the inaugural meeting of the Edmonton Branch in January 1956, I have a great interest in its progress and it was good to renew so many acquaintances from my earlier visits.

**COLD LAKE**

The great disappointment of the tour occurred on the following day, when I had planned a quick visit to Cold Lake. Fog prevented us from taking off from Edmonton till it was too late to make the trip worthwhile; moreover, even if I had pressed on to Cold Lake, it was very doubtful that I should have been able to get back. So we called the whole thing off.

I returned to Ottawa on the Sunday with my mission incomplete. To our members at Cold Lake I extend my apologies. I shall try to make another attempt to penetrate their remote fastnesses before long I hope.

**RESUME**

On a tour of this sort, with but a few hours to stop at each Branch, it is impossible to form any real assessment of the influence which a Branch exercises on its community and the work it is doing for its members. But certainly the superficial impression is that the Branches in the west are very active, they are well served by their Officers and appreciate the part they are playing in the work of the Institute as a whole. But they *do* suffer from a dearth of good speakers.

I know that the Halifax-Dartmouth Branch is similarly affected. Members, particularly members who are in positions of authority, are earnestly asked to remember this perennial need. Whenever they plan to travel or to send their specialists out, either east or west, they should get in touch with Mr. Orr of the National Programmes Committee or with me, and offer their services as speakers. In doing just this, in the cases of Mr. Wood and Dr. Cockshutt, Dr. MacPhail of the National Research Council did a very real service to the Institute.

Perhaps it will be an incentive to potential speakers if I say that I found no waning of the traditional western hospitality and friendliness. In this letter I cannot begin to express my thanks or even to mention those who went out of their way to be helpful and hospitable. Certainly anyone who once visits one of these Branches, as a speaker or merely as a guest, will want to do it again.

**ANNUAL DUES**

With a sharp change of subject, I should like to say something about annual dues. During March, dues bills are sent out to all members and I am glad to say that the majority are very promptly paid. They are paid so promptly and in such profusion that, in past years, our clerical staff has been overwhelmed with the necessary bookkeeping. This load hits us when we are particularly busy with the preparations for the Annual General Meeting and consequently, during April and May, some delay in the acknowledgment of dues is almost inevitable.

I mention this to ask your indulgence. Please do not get alarmed if several weeks go by between the mailing of your cheque and the receipt of your Membership Card for 1958-59.

**STUDENTS**

I should like to take this opportunity to remind Student members who graduated in 1957 that they must do something about their grading before the end of March.

After graduation, a Student is no longer "undergoing a course of study in a school of engineering or technology" and, therefore, he no longer qualifies for the grade of Student; however, the Council permits him to retain the grade until the end of the fiscal year in which he graduates, i.e. until the end of the following March. Before this time is up he must either apply for regrading or he must make a case for the retention of the grade of Student on the grounds that he is continuing full time academic studies — e.g. for his Master's degree. A member who continues full time post-graduate studies may be eligible for the grade of Technical Member but since he still complies with the qualifications for a Student he may retain the lower grade if he wishes to do so.

Students who graduated in 1957 and who have not already done something along the above lines run the risk of losing their membership altogether unless they take the necessary steps before the 31st March. Time is getting rather short.

# BRANCHES

**NEWS**

**Montreal**

Reported by F. M. Francis

*November Meeting*

The Montreal Branch held a dinner meeting on the 20th November in the International Aviation Building. Mr. E. H. Higgins, Chairman of the Branch, presided. LCDR J. J. MacBrien introduced the speaker, CDR H. J. Hunter, RCN, Naval Headquarters, Ottawa.

CDR Hunter spoke on the subject "Carrier Based Aircraft Operations with Special Reference to the Bonaventure". The 70 members and guests in attendance enjoyed CDR Hunter's description of carrier operations and during the question period that followed indicated their interest in this phase of aircraft work.

The speaker was thanked on behalf of the Branch by Mr. T. E. Stephenson.

*December Meeting*

On December 3rd the Montreal Branch held its annual Christmas social evening in the Town of Mount Royal Hall. One hundred and six members, wives and guests spent a pleasant evening dancing, dining and wining to the strains of an orchestra, which made up in enthusiasm what it lacked in numbers. Arrangements for the affair were capably handled by Messrs. C. G. MacLeod and J. D. Agnew.

*January Meeting*

The January meeting was held in the cafeteria of the International Aviation Building. It was preceded by a dinner, which was attended by approximately 75 members; an additional 40 members and guests assembled by the time the talk started. Mr. E. H. Higgins chaired the meeting. Mr. W. K. Ebel, Vice-President, Engineering, Canadair Ltd., introduced the speaker, Mr. A. T. Gregory, Chief Engineer, Fairchild Engine Division of the Fairchild Corporation.

Mr. Gregory defined the title of his paper, "Small Jet Engine", as one having a thrust between 1 and 3,000 lb. He pointed out that potential uses for these small engines lie in jet trainers, short haul feeder-line airplanes, army liaison craft, small personal airplanes, executive aircraft, intermediate range troop carriers and VTOL machines.

In developing their first engine, the J54, Fairchild drew on the experience of the manufacturers of large jets with the assistance of the USAF. This 1,000 lb thrust engine, designed initially for small subsonic missiles and target drones, has been awarded an Approved Type Certificate by the CAA as a thrust augmenter on large commercial aircraft. One experimental installation of this type is currently operated by an American airline.

Mr. Gregory cited the following as advantages of the small jet engine:

(a) simplicity,

(b) ease of handling and maintenance,

(c) low frontal area,

(d) multi-engine safety for the same power, and

(e) reliability equal to large engines.

On the debit side of the ledger, Mr. Gregory pointed out that small multi-engine installations require more plumbing, more instrumentaion and require special treatment in the aircraft wing structure, compared with a lesser number of large engines developing the same power. In addition, the same features that make the small engines attractive also limit their specific fuel consumption to values much higher than the large engines.

An active question period followed the talk. Mr. R. H. Guthrie, Engineering Manager, Canadian Pratt & Whitney, thanked the speaker at the conclusion of his talk on behalf of all those present.

**Edmonton**

Reported by C. W. Arnold

*December Meeting*

The Edmonton Branch held its December meeting on Tuesday, the 10th, in the RCAF Officers' Mess, RCAF Station Namao, at 7.30 pm, with 60 members and guests attending.

Mr. J. W. Bristow, Chairman of the Branch, presided.

A tour of the Station was made prior to the lecture by kind permission of G/C J. R. Frizzle. This tour was much appreciated by all the members who were able to inspect Javelin, Shackleton, CF-100 and Argus aircraft.

After a short business meeting, S/L J. E. Moran of the Central Experimental and Proving Establishment Detachment at Namao gave a brief summary of the current system of aircraft testing in the RCAF. He explained that in addition to doing acceptance tests on proven aircraft, the CEPE also perform the flight testing of new types. The current practice is to test concurrently several aircraft of the new type, each aircraft undergoing one aspect of the very comprehensive flight test programme. These phases include: contractors' initial tests; contractors' complete flight trials to prove performance and flight envelope; tests done by the CEPE to confirm the contractors' results and to establish the RCAF performance data and handling characteristics upon which to base pilots' operating instructions; climatic trials, armament evaluation and operational suitability trials. S/L Moran then amplified the role of the RCAF Climatic Detachment at Namao in connection with the climatic trials and explained the arrangement under which aircraft were tested for climatic suitability for the British Ministry of Supply.

The members were then transported to the CEPE hangar where they were shown some of the aircraft on current projects. Details of the aircraft were explained by F/L Deans, F/L Ovans, Lt. Reed (RN) and F/O Weinstein.

After a brief discussion period, Mr. H. Stapleton expressed the thanks of the Branch and the meeting was adjourned.

**Halifax-Dartmouth**

Although no regular reports on the activities of the Halifax-Dartmouth Branch have been submitted, Mr. E. C. Garrard, Chairman of the Branch, has recently given the following summary of their work during the current season.

*October Meeting*

This meeting was held on the 16th October, and the speaker was Surgeon LCDR H. D. Oliver, RCN, whose subject was "Accelerations and the Human Body".

*Special Meeting*

This meeting was held on the 29th October to meet the President, G/C H. R. Foottit, who was visiting the Halifax area. G/C Foottit spoke on the subject "Systems Engineering and Management". There was a record turnout totalling about 80 members and guests; many of the guests have subsequently applied for membership.

*November Meeting*

Mr. K. Roberts, Naval Research Establishment, spoke to the Branch on the subject of "Radiography" on the 20th November.

*December Meeting*

This meeting, held on the 18th December, was addressed by Mr. T. H. Rogers of the RCN Dockyard Laboratory, Naval Research Establishment, who spoke on "Corrosion Problems".

*January Meeting*

On the 22nd January, Professor Cochkanoff of the Nova Scotia Technical College, who was the original Interim Secretary of the Halifax-Dartmouth Branch, spoke to the Branch on the subject of "Inter-relation of Aerodynamics with Everyday Aeronautical Affairs".

Regular meetings have been well attended, with audiences including about 70% of the members of the Branch. Membership of the Branch now exceeds 50.

**Ottawa**

Reported by P. J. Pocock

*December Meeting*

On Wednesday, 11th December, Mr. C. D. Long chaired a meeting of the Ottawa Branch at which Mr. V. Koby, the Assistant to the President of Spartan Air Services Ltd., gave a talk entitled "Some Aspects of Natural Resources Survey Operations".

In his talk Mr. Koby covered in a general way some of the world wide aerial survey operations of his firm. Specifically he told of some of the problems of operating aircraft in the Arctic regions. After his talk Mr. Koby showed a short film covering some aerial survey work done in Malaya under the auspices of the Colombo plan; this was followed by a new film, The Map Makers, produced by Crawley Films Ltd. The latter film covers the broad field of work carried on by Spartan Air Services Ltd.

There was a turnout of 40 members for this talk and from the question period one could adduce that many in the audience had not only an interest but some considerable experience in aerial survey work.

The speaker was thanked by Mr. W. F. Campbell.

*January Meeting*

Sixty members turned out on Wednesday, 8th January, to hear Mr. W. W. Wood, Jr., talk on "The History, Philosophy and Economics of Flight Simulators". Mr. Wood is the Vice-President in charge of manufacturing at Link Aviation Inc., and formerly held the post of Vice-President in charge of engineering at this firm.

Mr. Wood mentioned the expanding field of application of simulators, giving some emphasis to the reduction in airline crew training expenses due to the introduction of aircraft simulators into an airline company's operation. Of particular interest to those of the audience who were not directly involved in simulator training devices was the fact stressed by Mr. Wood that the greatest amount of effort required in a training simulator was not involved with the computer section (for solving the differential equations of motion, say) but rather with the simulation of all the control systems and the like – what Mr. Wood called the "door bell wiring".

Mr. P. W. Larsen introduced the speaker and S/L M. T. Friedl thanked the speaker.

**Winnipeg**

Reported by R. R. J. Genno

*January Meeting*

About thirty members of the Winnipeg Branch attended the January meeting in the Westinghouse Auditorium on Tuesday, January 28th. A very welcome guest was the C.A.I. Secretary, Mr. H. C. Luttman, who, introduced by Professor C. M. Hovey, gave a short talk on various recent developments within the organization.

Guest speaker for the evening was Mr. A. D. Wood, head of the Flight Research Department of the National Aeronautical Establishment, Ottawa.

His subject was "Flight Research" and he made particular reference to the developments in flight research in Canada since the last war.

Early in his talk, Mr. Wood explained the difference between flight research and flight testing and went on to describe the function of his department and the various projects with which it has been concerned during the past few years. He referred to the tail-less glider, VTOL/STOL research and vortex generators, aerial detection and prospecting, repeating parachute, re-heat systems and helicopter icing research.

For most of his talk, he examined the development and purpose of the vortex generator, illustrating his talk with many interesting slides.

The speaker was thanked on behalf of the Branch by Mr. H. R. Eiler of Bristol Aircraft (Western) Ltd. The meeting closed with the showing of films on helicopter icing and re-heat systems.

**Vancouver**

Reported by R. W. Van Horne

*January Meeting*

The meeting was held at the Officers' Mess, RCAF Sea Island, on Wednesday, January 29th. Attending the meeting were 36 members and 5 guests.

Mr. H. C. Luttman, Secretary of the C.A.I., was in Vancouver doing some preliminary work for the Mid-season Meeting of the Institute, to be held at the Vancouver Hotel on February 28th and 29th. Mr. Luttman spoke of the coming Meeting and of the position being attained by the C.A.I. in the world of aeronautical societies.

The guest speaker of the evening, Mr. A. D. Wood of the Flight Research Section of the National Aeronautical Establishment at Ottawa, was introduced by the Chairman, Mr. H. H. Ollis. Mr. Wood's topic covered the possibilities and problems of flight research and of the value of such laboratory research in the saving of time and money by replacing the building of research aircraft to obtain similar data. The main point covered was the use of vortex generators on airfoil sections as the means of "Shock Wave" and "Boundary Layer" control at sonic and transonic speeds. Mr. Wood illustrated his talk with slides showing the various types of vortex generators which had been used in the wind tunnel and tests.

A film on the helicopter icing control experiments carried on by the National Research Council was shown, as well as a second film on "Screeching Combustion" in jet engines.

Mr. F. N. A. Ramsay thanked Mr. Wood for his informative talk on a subject that is becoming increasingly important.

The meeting adjourned at 11.00 pm.

# MEMBERS

**NEWS**

**G/C H. R. Foottit, F.C.A.I.,** formerly Director of Aircraft Engineering, has been appointed Assistant for Arrow Weapons System, a newly-created post at AFHQ.

**G/C E. P. Bridgland, A.F.C.A.I.,** has been appointed Director of Aircraft Engineering, AFHQ.

**J. Lukasiewicz, A.F.C.A.I.,** formerly with the National Research Council, has left Canada to take up a position as Chief, Gas Dynamics Facility, Arnold Engineering Development Centre, Tulahoma, Tenn.

**J. R. K. Main, A.F.C.A.I.,** has been appointed to the position of Director of Civil Aviation in the Dept. of Transport.

**J. J. Eden, M.C.A.I.,** has moved to Montreal where he has taken up the position of Trans-Canada Air Lines Powerplant Engineer.

**CDR E. B. Morris, M.C.A.I.,** has recently changed his position to that of Air Engineer Officer, RCN Air Station, Shearwater.

**H. R. Smith, M.C.A.I.,** has left his position as Vice-President Manufacturing at Avro Aircraft Ltd. to become Vice-President and General Manager of Dosco's new Steel Fabrication and Manufacturing Division.

**CDR N. A. Smith, M.C.A.I.,** has left Halifax to take up an appointment as Deputy Assistant Chief of Naval Technical Services (Air) in Naval Service Headquarters, Ottawa.

**S. E. Willis, Technical Member,** has recently resigned from Lear Inc. to take up a position with Boeing Airplane Co. at Renton, Wash., as an Associate Engineer Writer in the Service Dept.

**ADMISSIONS**

At a meeting of the Admissions Committee, held on the 16th February, 1958, the following were admitted to the grades shown.

***Associate Fellow***

**F. M. Francis** (on transfer from Member)

**R. C. C. Ringrose,** Group Leader, Structural Test Section, Canadair Ltd., Montreal, P.Q.: *955 Tasse St., Apt. 1, St. Laurent, P.Q.*

**H. L. Taylor,** Assistant Secretary, Canadian Aeronautical Institute, Ottawa, Ont.: *132 Clearview Ave., Ottawa 3, Ont.*

**H. H. Whiteman** (on transfer from Member)

***Member***

**Capt. J. D. Alexander,** Airline Pilot, Trans-Canada Air Lines, Toronto, Ont.: *280 Aldercrest Rd., Toronto 14, Ont.*

**Dr. E. Bendor,** Aerodynamacist, Canadair Ltd., Montreal, P.Q.: *3475 Ridgewood Ave., Apt. 205, Montreal, P.Q.*

**S/L E. A. Brain, RCAF,** SEGO/IE Branch Head, AMCHQ, Rockcliffe, Ont.: *542 Coronation Ave., Riverview Sub., Ottawa, Ont.*

**S/L D. L. Campbell, RCAF,** Project Engineer, Arrow Electronic System, RCAF HQ, Ottawa, Ont.: *974 Chapman Blvd., Ottawa 1, Ont.*

**W. A. Chisholm,** Liaison Engineer, Canadair Ltd., Dept. 744, Plant 1, P.O. Box 6087, Montreal, P. Q.

**F. H. Currie,** Service and Tech. Representative, Canadian Pratt & Whitney Aircraft Co., Ltd., Jacques Cartier, P.Q.: *196 St. Charles St. East, Longueuil, P.Q.*

**N. H. Davis,** Regional Manager, Sales & Service, De Havilland Aircraft of Canada Ltd., Room 31-32, T. C. A. Hangar, Edmonton Airport, Edmonton, Alta.

**F/L R. A. Doiron, RCAF,** Turbine Engine Specialist Officer, AMCHQ, Ottawa, Ont.: *214 Camelia Ave., Ottawa 2, Ont.*

**CDR A. J. Geraghty, RCN,** Deputy Assistant Chief of Naval Technical Services (Air), RCN HQ, Ottawa, Ont.

**D. G. Morris,** Project Electrical/Electronics Officer, VX-10, RCN Air Stn., Shearwater, N.S.: *P. O. Box 190, Shearwater, N. S.*

**D. J. Moss,** Engineer, Special Weapons Design, Canadair Ltd., Montreal, P.Q.: *205 Constantin, St. Eustache, P.Q.*

**T. R. Nelson,** Technical Officer OPS/AIG, International Civil Aviation Organization, Montreal, P.Q.: *420 Mount Stephen Ave., Westmount, P.Q.*

**N. S. Pearce,** Senior Test Engineer, Avro Aircraft Limited, Dept. 3110, Box 4004, Terminal A, Toronto, Ont.

**T. H. Rogers,** OC Naval Research-Dockyard Laboratory, Halifax, N. S.: *673 Quinpool Rd., Apt. 10, Halifax, N.S.*

**S/L R. E. Zwicker, RCAF,** Tech. Armament Officer, RCAF Stn. Cold Lake, Alta: *MPO 503, Grande Centre, Alta.*

***Technical Member***

**F/O A. L. Cunningham, RCAF,** Flying Instructor, RCAF Stn. Uplands, Ottawa, Ont: *384 Miller Ave., Eastview, Ottawa 2, Ont.*

**K. A. Mathison,** Engineer C, Canadair Ltd., Montreal, P. Q.: *1420 Ouimet, Apt. 22, Ville St. Laurent, P. Q.*

**Capt. K. R. Mattocks, RCA,** G-3 Directorate of Weapons and Development, Army Headquarters, Ottawa, Ont.: *856 Eastbourne Ave., Ottawa, Ont.*

**B. Pelipeyko,** Plant Supervisor, Carriere & MacFeeters Ltd., Scarborough, Ont.: *24 Wexford Blvd., Scarborough, Ont.*

**R. W. Sandford,** Stressman, Fairey Aviation Co. of Canada Ltd., Halifax, N.S.: *50 King St., Dartmouth, N.S.*

**LT (E) (AE) W. B. Shearer, RCN,** Shops Officer, Engineering Dept., RCN Air Stn., Shearwater, N.S.

**B. W. Spacey,** Draftsman, Canadair Ltd., Montreal, P. Q.: *4266 Old Orchard Ave., Apt. 1, N.D.G., Montreal, P. Q.*

**G. A. Stekl** (on transfer from Student)

**R. E. Stoddart,** Aircraft Inspector, Northwest Industries Ltd., Edmonton, Alta.: *8903 – 148th St., Edmonton, Alta.*

**I. A. Thomas,** Engineer A, Canadair Ltd., Montreal, P. Q.: *1895 Connaught St., Ville St. Laurent, Montreal 9, P. Q.*

**W. W. Throop,** Technical Liaison, Sub-Contract, Avro Aircraft Ltd., Malton, Ont.: *414 Rustic Rd., Weston, Toronto 15, Ont.*

**D. C. West,** Sr. Crew Chief, Sheet Metal Shop, Northwest Industries Ltd., Edmonton, Alta.: *11424–123 St., Edmonton, Alta.*

***Technician***

**L. A. Croucher,** Draftsman, Fairey Aviation Co. of Canada Ltd., Halifax, N.S.: *53 Evans Ave., Fairview, Halifax, N. S.*

**I. Floyd,** Draftsman, Canadair Ltd., Montreal, P. Q.: *5566 Decelles Ave., Apt. 7, Montreal, P. Q.*

***Student***

**Cadet V. Y. P. de la Durantaye,** Stone Frigate, Royal Military College, Kingston, Ont.

**Cadet S. R. Stankus,** Fort Haldimand, Royal Military College, Kingston, Ont.

# SUSTAINING MEMBERS

## NEW SUSTAINING MEMBER

The following Company has joined the Institute as a Sustaining Member:

**Phoenix Engineered Products Ltd.**

## NEWS

**Shell Oil Company of Canada Ltd.** announces two new developments of interest, one concerning high temperature greases and the other the use of roller bearings at high temperatures without any lubrication at all, other than a "protective atmosphere".

The high temperature greases, known as ETR (extreme temperature range) Greases, withstand temperatures up to 600°F and protect metal parts running at speeds up to 30,000 rpm. The lubricants contain an organic vat dye that serves as a thickener to improve heat stability and gelling efficiency. Company scientists began research on high temperature lubrication when it became apparent that the highest quality soap base and petroleum oil greases would be inadequate for the operating conditions met in extremely high speed flight.

The "protective atmosphere" for roller bearings has been developed from an investigation based on the theory that there is no metallurgical reason why roller bearings made of tool steel cannot operate satisfactorily up to at least 1,000°F – there are many examples of steel rolling successfully on steel without oil, notably the rolling of a railroad wheel on its rail. Theoretically there is no sliding friction between a rolling element and its race if point contact is assumed. In practice, however, a bearing and its race deform under load and therefore touch over a small area rather than a single point.

Early in the investigation, it was found that the deformation of the rolling element and its race is elastic. It was therefore concluded that no slipping occurs between the bearing and the race and that consequently no lubricant is needed to lessen sliding friction. Sliding does occur between the bearing cage and its rolling elements. Pressure on these sliding surfaces is very small, however, if a precision-made and properly aligned bearing is used. It was decided to investigate why bearings broke down when they were operated without oil or grease lubrication.

Tests were carried out on the cantilever end of a 10,000 rpm spindle, with the bearing held in a housing which could be electrically heated to 1,000°F. These tests at first produced very erratic results, even with very slight bearing loads, with bearings lasting from a few seconds to several hours. More consistent test results were achieved only after increased attention was given to the number of mechanical details. These included a far more critical bearing fit, alignment and cage balance than would have been necessary with conventional lubrication. It was also found necessary to "break in" bearings by operating them with oil lubrication before test runs.

Under these conditions, a definite performance pattern emerged. The investigators then learned that the bearing breakdowns were caused by iron oxide which formed during the dry operation and acted as an abrasive. Once formed, the oxide caused rapid wear of all bearing parts, resulting eventually in failure of the bearing. It was then decided to add to the air surrounding the bearing a substance which would attract the oxygen in the air, thus preventing it from attacking the bearing surfaces. A small amount of hydrocarbon vapour was found to have this effect and it then became possible to operate bearings for many hours without failure of the ball and race surfaces.

Failure did occur, however, as the result of scuffing or metal pickup on the rubbing surfaces of the cage. In conventional lubrication, scuffing is prevented by the use of "extreme pressure" additives which alloy with metal to provide a lubrication surface. The investigators found that if such additives were used during the "break-in" period and were then added in vapour form with the hydrocarbon vapour, a lubricating film developed on the rubbing surfaces of the cage and the rolling elements.

This process was called "protective atmosphere" lubrication. The method has been used successfully to operate bearings for 100 hours in temperatures approaching 1,000°F without any evidence of pending failure in the rolling elements, races and cages.

Regarding aircraft use, it is fortunate that JP-4, a widely used jet fuel, had been found especially useful in providing the "protective atmosphere" used in the bearing tests. The fuel was found to contain certain resins, which combine with extreme pressure additives to form improved lubrication films on the bearing surfaces.

Further work on "protective atmosphere" lubrication is being conducted.

**De Havilland Aircraft of Canada Ltd.** have announced the sale of four Otters to Qantas Empire Airways for use on the New Guinea Internal Air Routes.

The first aircraft, to be delivered early in May, will be an amphibious version which will act as a replacement for the Beavers and Catalina flying boats which have given such valuable service over the past few years. Qantas, therefore, will be the first Australian airline to operate an amphibian on scheduled services.

Based in Port Moresby, this Otter, fitted with floats and retractable main and nose wheels, will operate services to Papua, New Guinea and New Britain. Where it previously was necessary to use Catalina flying boats at ports depending on water alighting and Beaver aircraft for land operations, the advent of the Otter will eliminate route duplication, cut operating costs and ensure a greater frequency of services. The remaining three aircraft, scheduled for delivery in June and July, will be landplanes, one to be based at Port Moresby and serving the various airstrips along the existing routes to the east and west. The other two aircraft will replace the Beavers at present based at Lae.

There are over 200 Otters flying in world wide service, including a large number with the U.S. Army and Navy, and the United Nations. Recently an Otter from the British Antarctic Expedition became the first single engined aircraft to fly over the South Pole.

# BOOKS

**Engineering Thermodynamics.** By C. O. Mackey, W. N. Barnard and F. O. Ellenwood. John Wiley & Sons, Inc., New York, 1957. 428 pages. Illus. $7.95.

Based on an earlier work "Heat Power Engineering" by Barnard and Ellenwood, published in 1933, this book has been rewritten and brought up to date by the third author Mackey. The first six chapters cover basic principles and the main addition to the earlier book is a most useful chapter on the properties of real gases. The treatment of one-dimensional flow of ideal gases has been given more attention, as also the properties of gas mixtures and ideal gas reactions, including consideration of chemical equilibrium and dissociation.

The later chapters of the book deal with applied thermodynamics and here the aeronautical engineer will find some inadequacies. One and a half pages devoted to the axial flow compressor do not reflect the importance of this type nor has the chapter on turbines been revised to deal with the improvements achieved by the aircraft gas turbine, which has replaced the constant section bucket by the twisted aerofoil. Degree of reaction is still used in this book as an overall factor for a stage rather than a section parameter which varies from hub to tip. Also the idea that stage efficiency is reduced by complete loss of the energy of the leaving absolute velocity is a misconcept. In multistage turbines, this energy is carried over to the next stage and even in the final stage quite reasonable recovery is possible by proper exhaust diffuser design.

Apart from these criticisms, the book is clearly written and well illustrated. The exercises, with answers, at the end of each chapter should prove useful to the student.

F. H. Keast

**Transistor Circuit Engineering.** By R. F. Shea. John Wiley & Sons, Inc., New York, 1957. 468 pages. Illus. $12.00.

Since the introduction of transistors to circuit designers, a great need for uniformity of parameter symbols has existed, as we deal with a device that can be and is continually used in three configurations creating three sets of design parameters. In this book, a complete explanation of symbols has happily been placed in front of Chapter 1 and the symbols are used throughout the book.

The first three chapters contain basic design information which describes the relationship between physical parameters and design equations without resorting to basic physics.

Chapters 4, 5, 6 and 7 provide excellent information for design of amplifiers using the transistor as a linear device. Examples of audio, video, DC and feedback amplifier designs are given.

Chapters 8 and 9 provide oscillator, modulator, mixer and detector design information.

Chapter 10 is the largest single chapter in the book and is devoted to pulse circuits which have provided unlimited scope for the ingenuity of transistor circuit designers. Excellent material on basic design of circuits for computers and other pulse applications is provided.

Chapters 11, 12 and 13 cover specific applications of circuits described earlier in the book.

This book has been written by an extremely competent group of designers in this field. It fills a vacant spot in the library of all electronic applications and design engineers. The contents are easy to follow with references and type problems following each chapter.

The extensive bibliography at the end of the book becomes redundant when considered with the references at the end of each chapter and also adds one more apparently inexhaustible source of information to the already confusing array of bibliographies available in this field.

This book will remain an excellent source of design information for some time to come.

G. M. Kerrigan

# APPOINTMENT NOTICES

*The facilities of the Journal are offered free of charge to individual members of the Institute seeking new positions and to Sustaining Member companies wishing to give notice of positions vacant. Notices will be published for two consecutive months and will thereafter be discontinued, unless their reinstatement is specifically requested. A Box No., to which enquiries may be addressed (c/o The Secretary), will be assigned to each notice submitted by an individual.*

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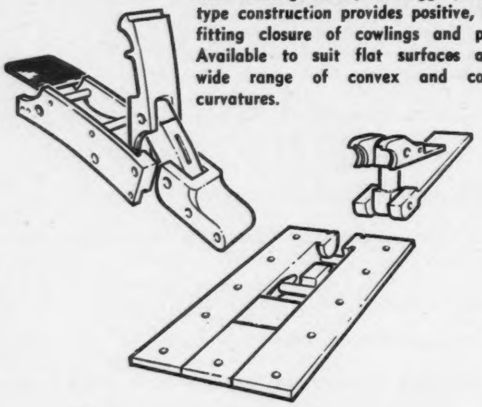

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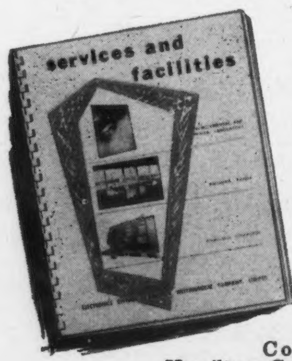


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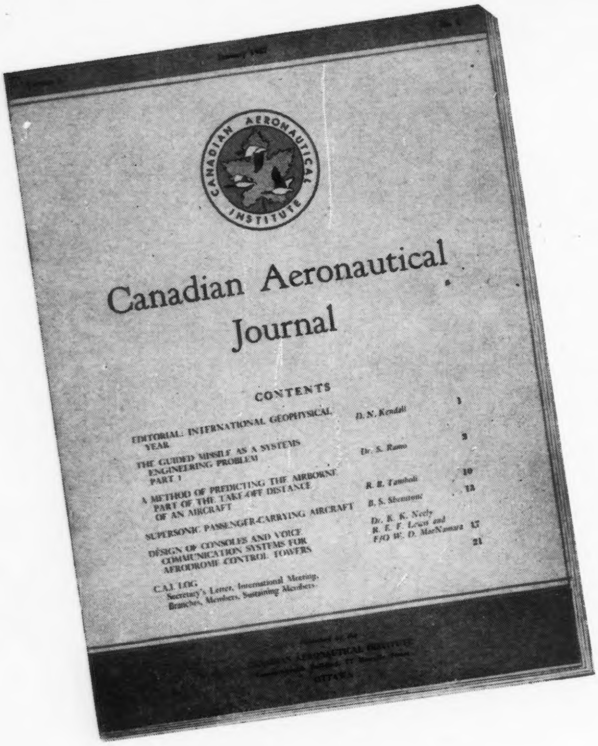


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Lockheed CL-329 Jetstar (Prototype)

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| Lockheed CL-329 Jetstar (Prototype)* | US |

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| | |
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| North American Model 249 (alternative engine)* | US |
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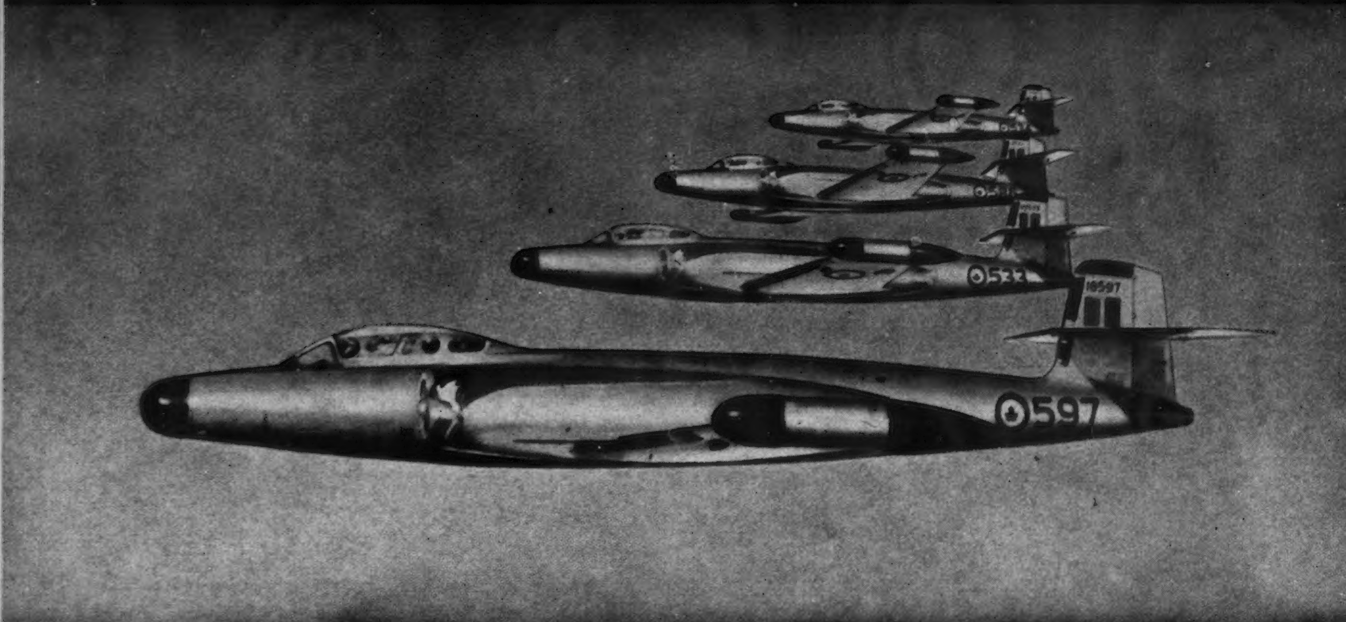


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